SCIENCE & TECHNOLOGY

Journal of the AIR POLLUTION CONTROL ASSOCIATION

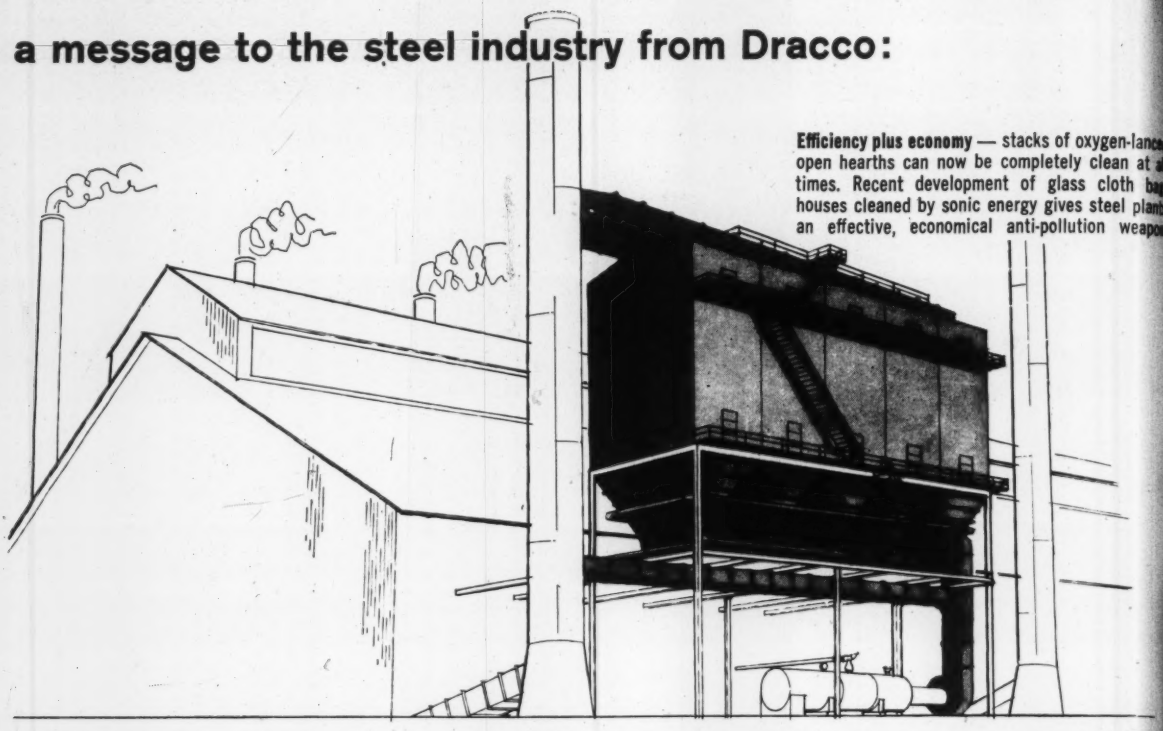
STACKS

Founded 1907

May 1961
Vol. 11, No. 5

Empire State Building and "Nightline" of New York.
Courtesy of New York Convention and Visitors Bureau.

a message to the steel industry from Dracco:



Efficiency plus economy — stacks of oxygen-lanced open hearths can now be completely clean at all times. Recent development of glass cloth baghouses cleaned by sonic energy gives steel plants an effective, economical anti-pollution weapon.

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• **Lower capital investment** can mean 33⅓ to 50% savings compared to less efficient, more costly devices currently used.

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• **Extremely high efficiency** stays high at all times, regardless of fluctuations in dust and furnace conditions. Discharge free of visible solids can mean a clean stack for your plant.

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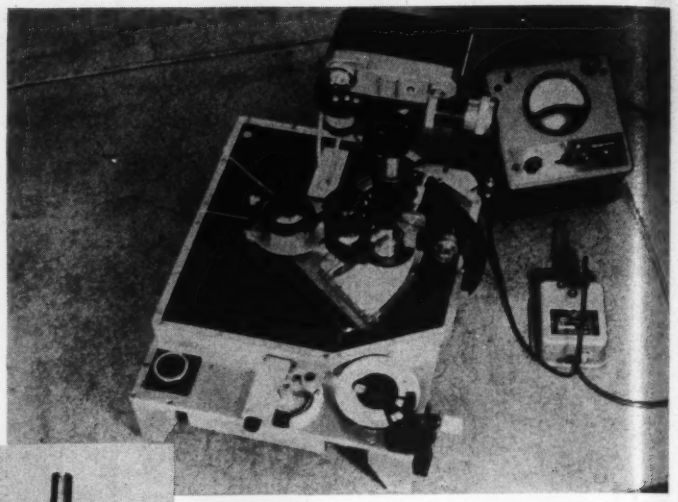

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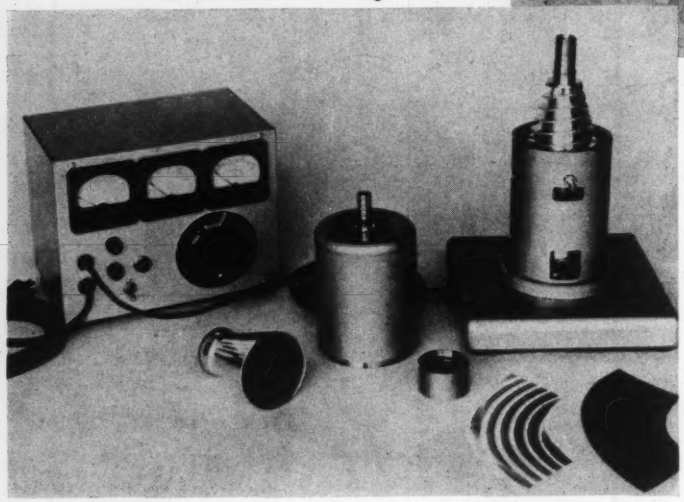

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

A Monthly Journal
Devoted to
Air Purification

Editor: Arnold Arch
Associate Editor: Pat Truschel
Assistant Editor: Pat Martin

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AIR POLLUTION CONTROL
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Pittsburgh 13, Pa.

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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LETTERS to the EDITOR

Criticism Answered

Editor:

I have been caught out on a limb of Parson Weems' cherry tree!

Mr. Erwin K. Kauper's criticism of my use of a "quotation" by Richard Henry Dana regarding smog in Los Angeles back in 1834 is correct—Dana never said it.

An intensive study by my researcher has revealed that the paragraph first appeared under the title "Unheard-of-Quote" in a publication of the Western Oil and Gas Association in 1959. It was used, as authentic, in a speech made shortly thereafter by a California state official. I picked it up at third hand and used it in my Cincinnati speech. So does folklore have its origins!

I can only add, in partial extenuation, that Bartlett's "Familiar Quotations" seems to be guilty of a similar slip regarding Dana. It prints a "quote"—and a good one, too—from his "Twenty-Four Years After," supposedly written in 1869. Yet neither the New York Public Library Catalogue nor the Library of Congress Catalogue lists any such book or article.

Finally, the position of pharmacist's mate on U. S. Naval vessels was established by an Act of Congress on March 2, 1799, while the U. S. Weather Bureau tells us that the term "inversion" has been in use for so many years that the date of its origin cannot be established. All of which gives the Dana quote a ring of authenticity to my history-gullible mind.

I assure Mr. Kauper that I will do my utmost to scotch further use of this misquotation and gladly join hands with him in the inexorable march toward cleaner air and historical accuracy.

Sincerely,

G. A. LLOYD, *Chairman*
Information Committee
Air and Water Conservation Committee
American Petroleum Institute

Cleaner Air Week Fan

Editor:

I am one of those so-called aroused citizens hoping to join and actively support "Cleaner Air Week," the nationwide activity which you sponsor every October. However, I am not satisfied nor content to wait until October to start supporting such a fine Association as yours.

(Continued on p 199)

SECRETARY'S PAGE

New York–54th Annual Meeting

Each year APCA holds its annual meeting and exposition in various centers of industry. This year New York City has been chosen as the meeting's headquarters. It is important to recognize the objectives:

1. Furnish the common grounds for the exchange of technical information.
2. Stimulate development progress.
3. Document the year to year progress in the constantly expanding field of air pollution control.

The technical program, under the capable guidance of George T. Minasian, Director of Community Relations for Consolidated Edison Company of New York, as Technical Program Chairman, is extremely well organized. APCA is combining forces with two other outstanding technical groups to bring its members, and to attract nonmembers, to the technical sessions. Joint sponsorship with the Instrument Society of America brings 10 outstanding papers concerning the latest developments in the highly important and fast developing area of measurement of air pollutants. The Manufacturing Chemists Association has joined APCA in obtaining four prominent figures for the keynote session which will be devoted to the various aspects of ambient air quality standards. In planning the remaining portion of the program George T. Minasian and his committee have not overlooked any of the diversified areas of interest represented by APCA's membership.

Reprints Available

During the annual meeting at Cincinnati 66 of the 70 papers delivered were available through the preprint booth. It is expected that even a better record will be achieved with the co-operation of the authors this year. At Cincinnati in 1960 approximately 4000 papers were distributed at the preprint booth. Once again, registration will include 12 tickets to each registrant toward buying 12 preprints.

Publication of Proceedings Discontinued

Upon the recommendation of the Editorial Review Committee and the Publications Committee no proceedings will be published for the 1961 annual meeting. APCA's proceedings have been merely a compilation of the annual meeting papers—not then a true "proceedings." The amount of time and money being devoted to the publication of the proceedings can better be spent in improving the quality and number of pages in the JOURNAL. Consequently, the Board has approved the discontinuance of the publication of the proceedings. Another reason for this decision is occasioned by increased frequency of the JOURNAL on a monthly basis.

Visit the Exhibits

Once again, under the guidance of Nicholas K. Post, Airkem Corporation, who is the National Exhibits Chairman, with the co-operation of equipment and instrumentation manufacturers has assembled another fine exposition. The exposition gives to the exhibitors the opportunity to display their newly developed capabilities and products to the high caliber of air pollution control specialists from industry and government who attend APCA's annual meetings. In addition, income derived from the exposition helps underwrite many of the expenses for the annual meeting.

Entertainment

Arthur J. Benline as General Conference Chairman, along with his local committee, has planned an outstanding entertainment program for both men and women attending the annual meeting.

Letters to the Editor

(Continued from p 198)

Perhaps you are wondering how I found out about your organization. From a very well-written article, "How to Protect Yourself from Air Pollution," by Eugene A. Sloane, in the January '61, issue of *House Beautiful Magazine*. Mr. Sloane states that your association would be very glad to supply me or any other interested person with technical information about air pollution.

Please don't make it too technical though, as I am only twenty-one and possibly wouldn't be able to persuade the influential people of a community to believe such facts. The truth is—maybe I myself could not comprehend or understand too technical of terms—how then could I relate them to others who are not as well informed.

Would greatly appreciate any help or knowledge you could give me. Are there any special books one could read or pamphlets one could send for in order to get a better understanding of this subject and thus be able to put his ideas across without misconception?

I know I can count on a few supporters but, how can one go about starting a Citizens' committee to have an air pollution control ordinance enacted? Would you, by any chance, know someone I could write to who has started such a committee and would be willing to explain how he or she went about it?

Thanking you for taking your time to read this letter and hoping to hear from you very soon, I remain—An Angry Young Woman Supporter.

Very truly yours,

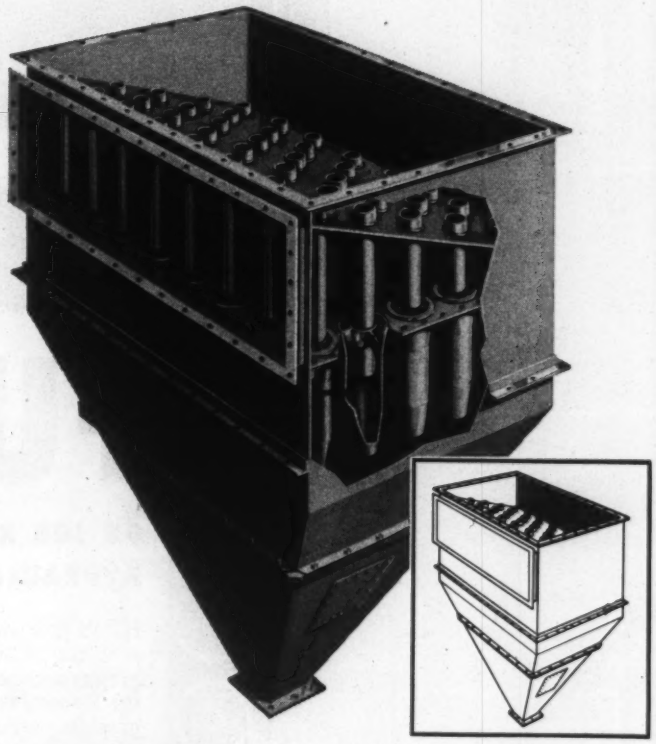
(Miss) Grace F. Houterloot

P.S. Can't promise you any miracles but would like you to know that I will sincerely try to help in the fight for "Cleaner Air."

CLASSIFIED

OPPORTUNITIES FOR SCIENTISTS IN AIR POLLUTION RESEARCH PROGRAM — Chemical Engineers — Chemists — Industrial Hygienists—are you interested in locating, identifying, quantifying gases and related pollutants with the objective of improving the quality of the air we breathe?—If so, we're interested in *you*. We have a big, challenging job to do. We are inviting men with appropriate scientific and report-writing skills to work with us. Salary about $9,000 to $10,600, with Civil Service benefits and requirements. Write Director, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

New Ideas On Dust And Fume Control



New Products:

John Wood Improved Cyclone Collector

New collector tube and inlet vane designs in the John Wood Cyclone Collector result in sharply increased operating efficiency. These improvements enable the John Wood engineered equipment to provide the uniform gas flow to each cyclone and to assure the high centrifugal force necessary to remove even the smallest particle sizes.

All steel construction and 9" diameter cast tubes and vanes mean high resistance to high temperatures and severe abrasion. A full range of special casting materials meets even the most severe requirements. John Wood Cyclone Collectors are compactly designed and simple to install. Several duct connections and a wide variety of tube arrangements are available to handle gas volumes up to several hundred thousand CFM.

New Engineering: **The complete line of John Wood equipment also includes Flooded-Bed Scrubbers, Venturi Scrubbers, Involute Cyclones, Fabric Filters and combination units. Extensive John Wood laboratories are available for advanced research on your air pollution problems.**

New Service: **John Wood Air Pollution Control is fully programmed from analysis of existing conditions to equipment installation. Frequently economies result that make the installation self-liquidating through lower maintenance and replacement costs.**

Write for engineering assistance or specific product information. An air pollution preliminary analysis kit is available without obligation.

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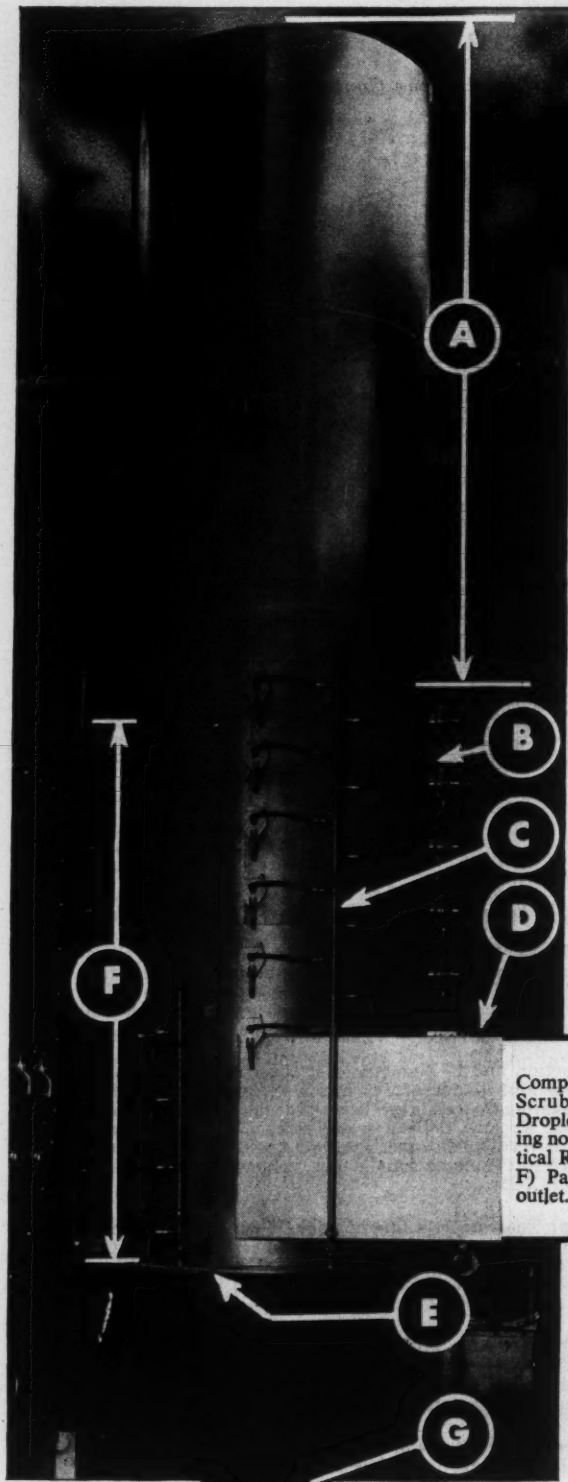

DENSE FUMES

ON JOB REMOVED BY 'BUFFALO' HYDRAULIC SCRUBBING TOWERS

Here's how an aircraft plant solved a critical contaminant problem. 35,000 and 50,000 ton hydraulic, closed die forge presses are used to produce large aluminum components for the aircraft industry. Fumes (dense smoke, oil mist and graphite particles) are released as the presses are operated.

Four specially-designed 'Buffalo' Hydraulic Scrubbing Towers were utilized. Each is rated at 65,000 CFM and 1.5" w.g. The spray system recirculates 250 GPM at 100 psi.

Before installation, the entire work area was completely covered with an oil slick. The stack effluent was termed a nuisance. Since installation, the work areas are clean. The stack effluent is negligible. Operation of the 'Buffalo' Hydraulic Scrubbing towers and laminates over 90% of the contaminants.

Component parts of the 'Buffalo' Hydraulic Scrubbing Tower are: A) Collection and Droplet Elimination Section. B) Quick-opening nozzle latches with flexible piping. C) Vertical Risers. D) Inlet. E) Spray manifold ring. F) Particle conditioning section. G) Waste outlet.

'Buffalo' Hydraulic Scrubbing Towers are high efficiency, wet centrifugal air cleaning devices specially designed to solve your fume removal problems.

They utilize : 1) A finely atomized spray system for particle conditioning. 2) Inertial separation of the contaminant from the gas stream in a cylindrical tower.

Whatever your air pollution problem, call in your 'Buffalo' resident engineer. He will be glad to help you solve it — efficiently, economically.

"Buffalo"

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Buffalo, New York

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East Central Section Annual Technical Meeting—September 21, 22, 1961, Louisville, Kentucky

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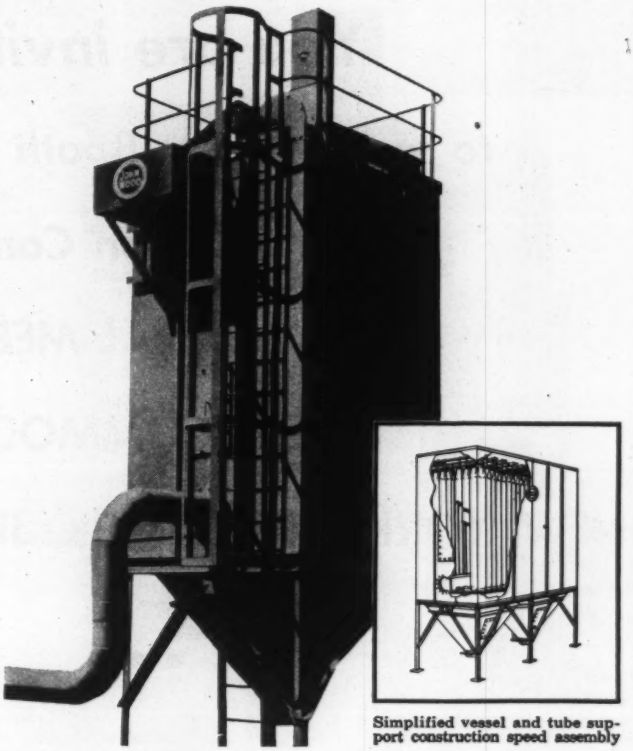
For further information write to Ralph W. Bourne, Room 2, City Hall, Louisville 2, Kentucky

New Ideas On Dust And Fume Control



Simplified vessel and tube support construction speed assembly

New Products:
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John Wood Fabric Filters are engineered for 99.9% efficiency in addition to trouble-free operation. They are the result of a program to design equipment for fully effective removal of all dry dusts at elevated operating temperatures.

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New Engineering: John Wood Fabric Filters are but part of the complete line. Other equipment includes Interphase Reaction Scrubbers, Multi Cyclones, Involute Cyclones, Venturi Scrubbers and combination units. New designs are now under development.

New Service: John Wood Air Pollution Control is fully programmed from analysis of existing conditions to equipment installation. Frequently economies result that make the installation self-liquidating through lower maintenance and replacement costs.

Write for engineering assistance or specific product information. An air pollution preliminary analysis kit is available without obligation.

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Air Pollution Control

54th ANNUAL MEETING

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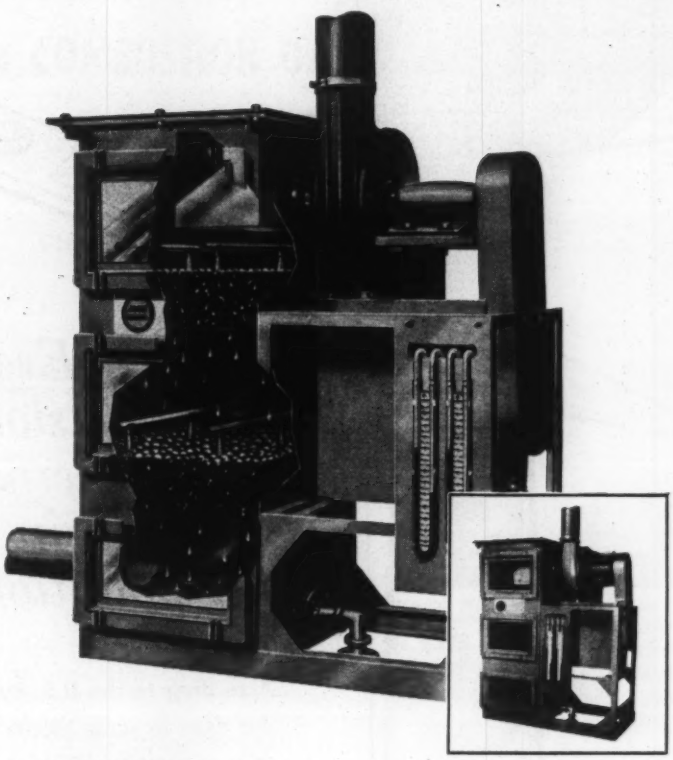
Palo Alto, California

In Memoriam . . .

We regret to announce that A. P. Everstine, Secretary-Treasurer, Schaefer Equipment Company of Pittsburgh, Pennsylvania, died February 24, 1961. He was a member of the Tellers Committee.

New Ideas On Dust And Fume Control



New Products:

John Wood Interphase Flooded-Bed Scrubber

This unique approach to the removal of fumes, vapors and dust from ventilation systems offers a new high in operating efficiency. In fact, efficiencies in adsorption and absorption of NO_2 exceeding 95% and of HCl of virtually 100% have been obtained.

Two horizontal beds operating under flooded conditions break the air stream into bubbles 1/16 inch in diameter. Completely surrounded by the scrubbing liquid and subject to impaction forces caused by continuous change of direction, the bubbles break up. Rapid absorption is the result.

The John Wood Flooded-Bed Scrubber is a compact, integrated unit. Construction is corrosion proof and provides easy access for servicing.

New Engineering: The complete line of John Wood equipment also includes Venturi Scrubbers, Multi Cyclones, Involute Cyclones, Fabric Filters and combination units. Extensive John Wood laboratories are available for advanced research on your air pollution problems.

New Service: John Wood Air Pollution Control is fully programmed from analysis of existing conditions to equipment installation. Frequently economies result that make the installation self-liquidating through lower maintenance and replacement costs.

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Every Morse Boulger Custom-Engineered Incinerator has built-in air pollution control . . .

According to the U.S. Public Health Service you take in some 15,000 quarts of air per day. *This is 10 times as much by weight as your intake of food and water combined!* This startling fact underscores the vital importance to your health of efficient air pollution control measures.

Every Morse Boulger incinerator installation (from giant municipal plants to compact industrial units) is *custom-engineered* to make a significant contribution to the public health because of *built-in air pollution control.*

Our engineering staff (with a background of more than 70 years' pioneering in air pollution control) is available at all times for consultation, without obligation, to help solve *any* incineration problem *whatever it may be.*

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SCRUBBING of FUME from COMBUSTION GASES at Efficiencies up to 99.98 Percent*

GLEN M. HEIN and ALEXANDER R. ORBAN, Battelle Memorial Institute

In 1956, the aircraft-propulsion-testing facilities of the U. S. Air Force at the Arnold Engineering Development Center[1] near Tullahoma, Tenn., were in need of modifications which would provide for the test burning of boron-containing fuels in the full-scale, experimental engines then being developed. The large concentrations and quantities of boric oxide fume in the products of combustion from these new fuels would present two serious problems if high-efficiency collection of fume could not be obtained within the limited space available for gas cleaning equipment.

The problem of air pollution was obvious. Equally alarming, however, was the prospect of fouling the huge axial-flow exhausters which maintain high vacuum for simulated altitude conditions in the engine test cells. Fortunately, a large supply of spray water was already installed for thorough cooling of the exhaust gases from hydrocarbon-fueled engines to temperatures below 90°F. A consideration of possible gas cleaning methods soon led to the conclusion that wet scrubbers would be the most feasible means for this application.

The experimental work described in this paper was done by Battelle for the Arnold Engineering Development Center. Its purpose was to evolve suitable methods and operating conditions for cleaning exhaust gases containing boric oxide fume. Companion research[2, 3] of a similar nature using larger equipment and including operation at subatmospheric pressures was also done by ARO, Inc., Tullahoma, Tenn.

Although this work was carried out in connection with a jet-engine test facility, the results obtained should be applicable to other processes in which gases or air are contaminated with submicron fume particles which must be removed from the gas stream to prevent pollution of the atmosphere.

* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

Description of Laboratory Fume Generator and Scrubbing System

The first objective of this investigation was to determine the capabilities and limitations of the existing exhaust-gas-cooling system with respect to the removal of boric oxide particles from the gas. The second objective was to improve the collection efficiency by investigating and changing the operating variables which contributed most to the cleaning process.

To accomplish the above objectives, an experimental scrubbing system was designed and built with a configuration similar to the ducting in the test facility at Arnold Engineering Development Center. The laboratory scrubber was designed to simulate gas velocity, gas temperature, subcooler-spray droplet size, spray-nozzle pressure, spray-nozzle direction, and weight ratio of subcooler water to exhaust gas that existed in the test facility. In the last part of the investigation, the hot-gas velocity was increased to Mach 1 at the discharge of the burner in order to simulate conditions at the tail pipe of a jet engine. All experiments in the laboratory model were conducted at atmospheric pressure.

Figure 1 shows the laboratory equipment which made up the experimental scrubbing system that was used during the experiments. Figure 2 is a schematic flow diagram of the experimental scrubbing system that was used.

Boric oxide fume was generated by burning a 70–30 mixture of trimethylborate and methanol which was sprayed from a fuel nozzle into a tubular, refractory-lined combustor. Although the boric oxide loading in the products of combustion from the 70–30 azeotrope was lower than that obtained from fuels of higher boron content, the azeotrope represented a suitable substitute for the more expensive and less available fuels because of similar characteristics of the fume.

The azeotrope produces approximately 0.04 lb of boric oxide per pound of exhaust, or 22 grains per standard cubic foot, when burned stoichiometrically with air. Loadings of from 0.01 to 0.023 lb per pound of combustion gas were obtained from the laboratory combustor.

The long scrubbing duct which followed the combustor was designed to duplicate on a laboratory scale the configuration of water sprays, duct bends, and water-droplet separator which existed in the test facility. Therefore, the first spray location for evaporative cool-

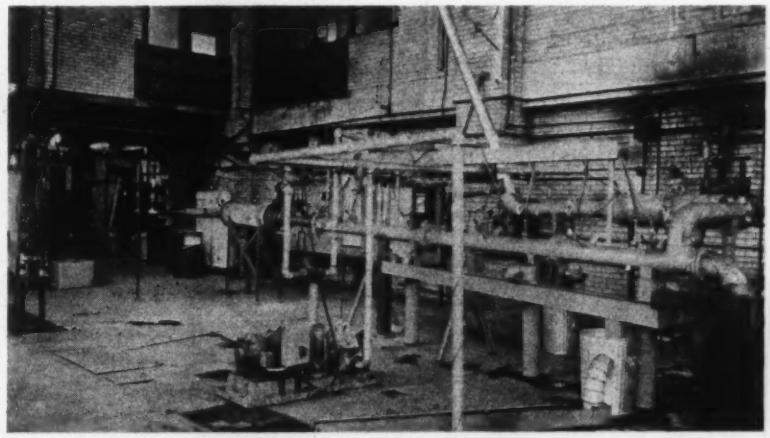


Fig. 1. Laboratory experimental scrubbing system.

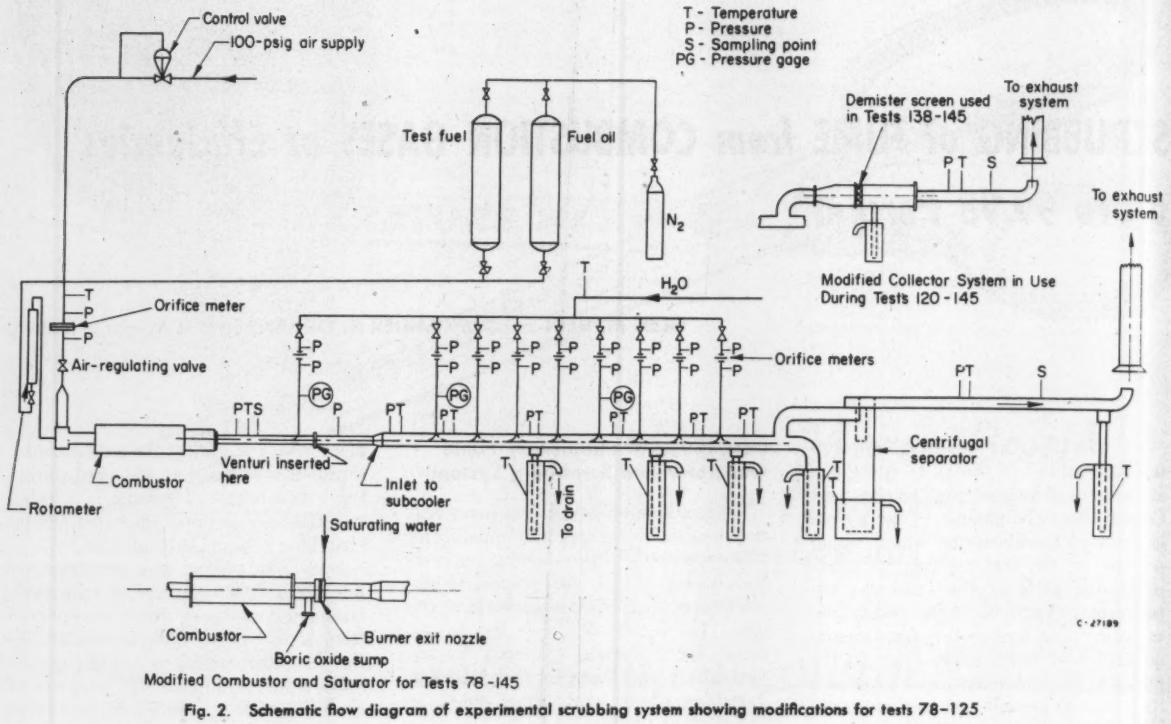


Fig. 2. Schematic flow diagram of experimental scrubbing system showing modifications for tests 78–125

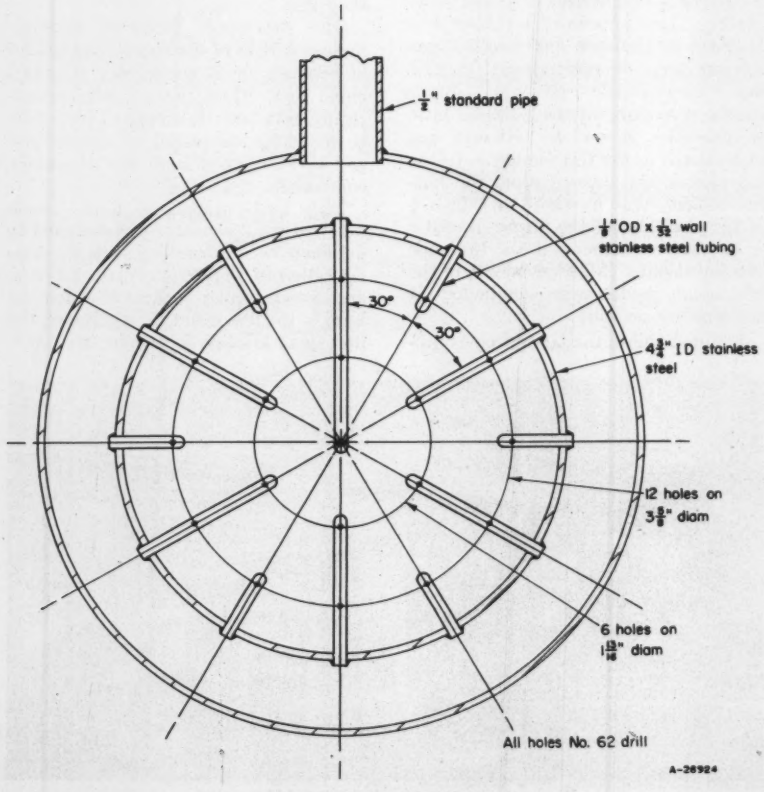


Fig. 3. Saturating spray bar.

ing of the exhaust gases to saturation temperature was followed by eight water sprays in series in the subcooler.

The first section of the duct (precooling and saturating section) was an eight-foot length of 4.75-in.-ID stainless steel tube which contained the first cooling-water spray. Transition to a 6.06-in.-ID subcooling section was made to simulate the ratio of duct sizes in the test facility. In the subcooling section the nozzles were installed axially at two-foot intervals, beginning three feet from the inlet.

Experiments were conducted with the nozzles pointed upstream and with the nozzles pointed downstream. Water for the nozzles was supplied from a plant main capable of delivering 110 gpm at 100 psig. This provided a water-to-gas weight ratio of approximately 23 to one at maximum air-flow rate. Water flow to each nozzle was measured by a standard ASME sharp-edge orifice meter. Water was drained by gravity from the subcooler through a number of water-seal legs.

To eliminate water-droplet carry-over from the system, a stainless steel cyclone separator was used. Design calculations indicated that the cyclone would collect particles of a size of 10 microns and larger.

Combustion air was supplied from the laboratory air system and was

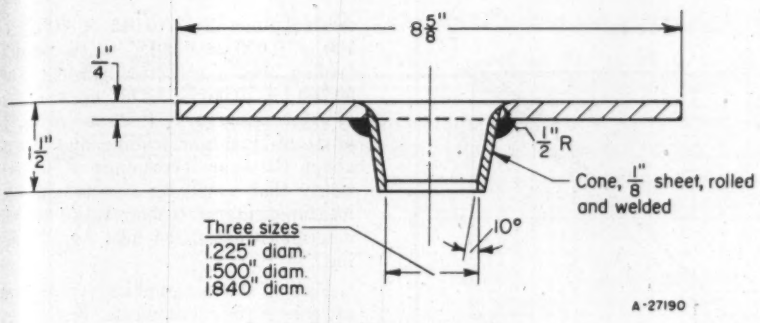


Fig. 4. Typical burner exit nozzle.

measured by a calibrated ASME orifice meter. Temperature and static pressure were measured at several points in the flow system as indicated in Fig. 2.

During the early runs at low hot-gas velocities, three types of commercial spray nozzles were tried in an axial position pointing upstream in the precooling and saturating section, but, because of the wide conical spray pattern and the coarse drop size, much of the water reached the walls of the duct before complete evaporation took place. To eliminate this condition, a spray bar, shown in Fig. 3, was installed in the saturating section to introduce water axially into the gas stream. This was used during tests at hot-gas velocities of up to about 0.1 Mach No.

In an attempt to improve collection efficiency further, the spray bar was replaced by a venturi which was inserted into the 4.75-in.-diam section. It consisted of a $2^1/_2$-in.-diam-throat section with a 15-degree tapered inlet and a four-degree tapered outlet. Saturating water was introduced radially around the throat through 26 holes $^1/_{16}$ in. in diam.

For later experiments at burner exit velocities up to Mach 1.0, an Inconel section six in. in diam and 12 in. long was attached to the downstream end of the combustor, and the pressure in the combustor was increased to obtain critical pressure ratio across an exit nozzle for sonic discharge velocity.

Figure 4 shows a typical nozzle that was secured to the discharge end of the Inconel section.

Figure 5 shows the saturating spray ring used to inject water radically into the high-velocity gas stream $^1/_2$ in. downstream from the end of the nozzle.

In later test runs, the centrifugal separator which was located at the end of the scrubbing system was removed because the high-pressure drop at high mass air flow rates caused the water-seal legs to blow out. This was replaced by a 12-in.-diam demister screen which is shown in Fig. 2.

Methods for Evaluating the Scrubbing Process

The collection efficiency of the fume-scrubbing process can be determined by measuring at least two of the quantities in the following expression, which represents a material balance for the fume:

$$A = B + C$$

Where:

A = fume entering the scrubber
B = fume removed in the scrubber
C = residual fume in the effluent gas.

In this study all three quantities were expressed as a loading in pounds of boric oxide fume per pound of dry clean gas, which provided a constant denominator throughout the scrubbing process. Quantity A was calculated from measured air and fuel rates and the combustion equations for the boron-containing fuel burned in the combustor. The residual fume (Quantity C) was measured directly by sampling the effluent gas, passing it through an efficient filter, and titrating the boric acid in the water used to wash the filter assembly. The fume removed by the scrubbing water (Quantity B) was also determined in some of the tests by titrating the boric acid in a sample of the effluent water and making a material balance on water entering and leaving the scrubber.

Collection efficiencies were calculated by the following expressions:

$$\frac{A - C}{A} \times 100 = 100 - 100 \times \frac{C}{A}$$

$$= \% \text{ collection efficiency} \quad (1)$$

$$\frac{B}{B + C} \times 100 = \% \text{ collection efficiency} \quad (2)$$

The collection efficiencies shown in Figs. 9 through 21 were calculated by Expression (1).

Special attention was given to the measurement of residual fume loading in the effluent gas, as this value by itself was the principal criterion of a scrubber for the test facility at AEDC.

Figure 6 shows the first version of the apparatus used for sampling the effluent gas. The sampling probe at the left was quickly inserted into the six-inch exit duct (not shown), and the vacuum pump was used to draw a measured flow of gas at a constant rate through the

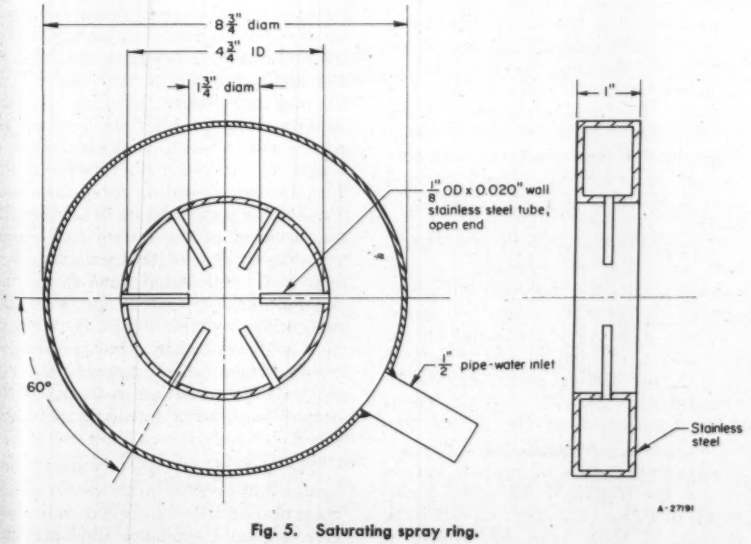


Fig. 5. Saturating spray ring.

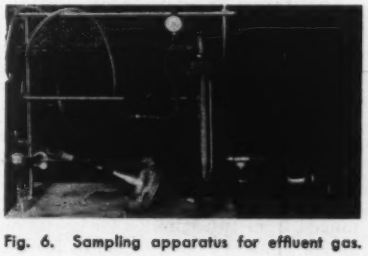


Fig. 6. Sampling apparatus for effluent gas.

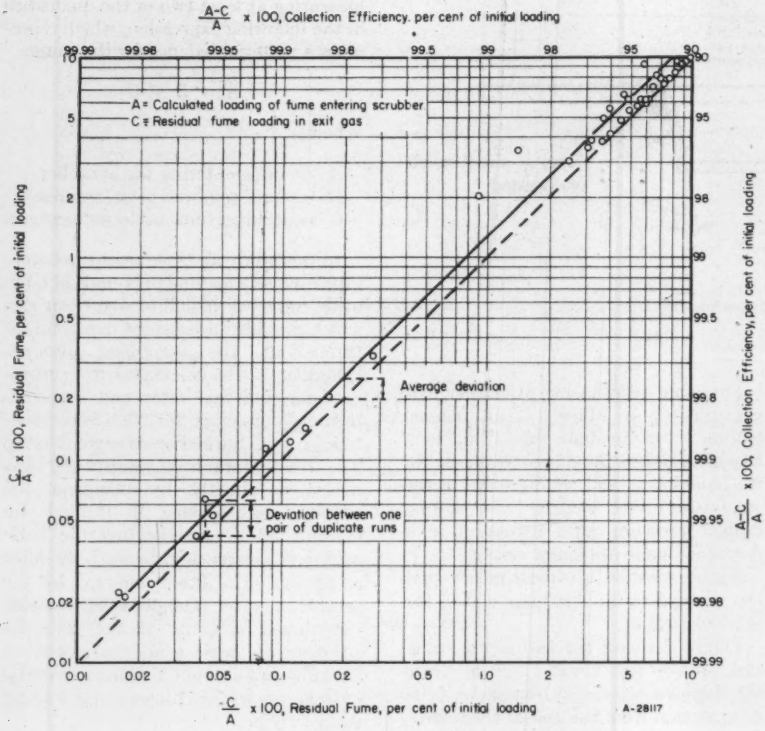

A-C/A x 100, Collection Efficiency, per cent of initial loading
A = Calculated loading of fume entering scrubber
C = Residual fume loading in exit gas
Average deviation
Deviation between one pair of duplicate runs
C/A x 100, Residual Fume, per cent of initial loading
A-C/A x 100, Collection Efficiency, per cent of initial loading
C/A x 100, Residual Fume, per cent of initial loading
A-28117

Fig. 7. Comparison of results from duplicate test runs.

glass impinger containing distilled water. From the impinger the gas entered the funnel-shaped filter holder, which contained either two Millipore papers or an all-glass fine-fiber paper followed by a Millipore paper. The papers had a filtering diameter of $4^1/_2$ in. The wet impinger was later eliminated from the sampling train after duplicate checks showed that it did not increase the amount of fume collected by the train. It was also found that the use of a glass-fiber filter ahead of the Millipore paper avoided rapid increase in pressure drop, and that the use of a second Millipore paper in series did not increase the amount collected. Titrations of wash water from the downstream half of the filter holder and exit tubing also showed no deposit of boric oxide. As a result of these tests, one glass-fiber filter paper and one HA Millipore paper with backup paper were used ahead of the metal supporting screen in the filter holder during subsequent test runs.

During each sampling period, the rate of gas flow in the probe was kept constant at approximately isokinetic flow conditions by using a sampling probe of suitable size and a suitable sampling rate for each of the three nominal airflow rates employed. Sampling flows of from 0.5 to 0.8 standard cubic foot per minute were used, and the duration of sampling ranged from two minutes for operation at low efficiency to 30 minutes for the higher efficiencies. At the lower efficiencies, sampling was stopped when the pressure drop across the filter began to rise sharply.

The boric oxide fume was recovered from the sampling train by transferring the filter paper to a titration flask into which the hot wash water from the entire train was then added. The determination of boric acid by titration was carried out by the usual method of fixing the pH of the solution with hydrochloric acid or sodium hydroxide (paranitrophenol indicator), boiling to drive off carbon dioxide, adding mannitol, and titrating to the phenolphthalein endpoint with sodium hydroxide. To obtain net titration values for each daily set of samples, a blank determination was made by titrating an equal volume of water that contained unused Millipore and glass-fiber filter papers.

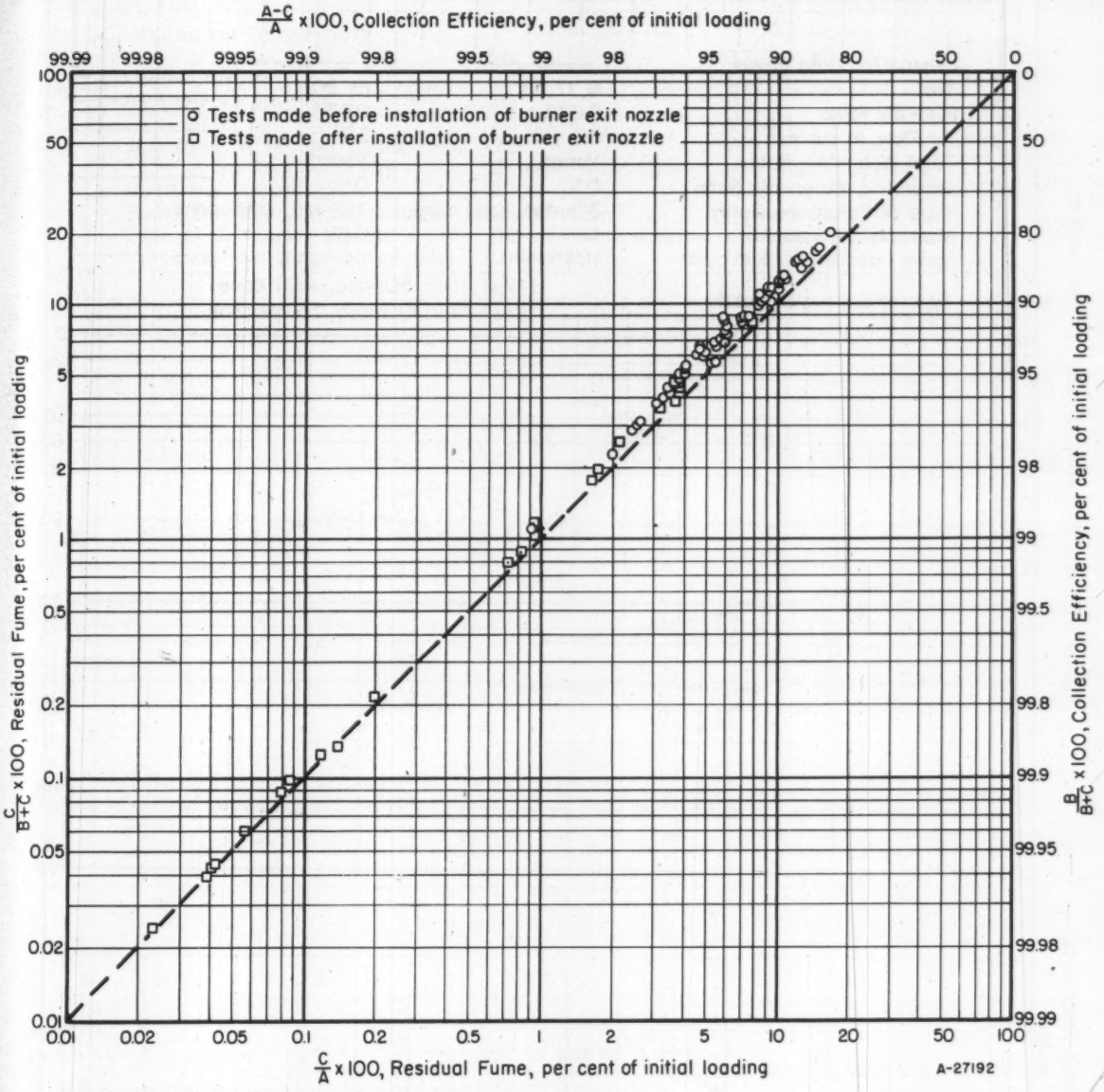
In regard to the accuracy of the titration, and thus the accuracy of calculated results for collection efficiency, several checks were made. Prepared solutions of boric acid containing known amounts of from one to two milligrams of B_2O_3 per 100 ml were titrated by two different analysts, and the maximum deviation from the known was 0.1 milligram. At the highest collection efficiencies obtained, a 30-minute sample of exit gas contained 2.0 ± 0.1 milligrams of B_2O_3. This gave an exit fume loading of three ppm by weight, a residual fume of $[3/(0.015 \times 10^6)] \times 100 = 0.020 \pm 0.001\%$ of the initial loading, and a collection efficiency of 99.980 ± 0.001%. The uncertainty of ±0.1 milligram in this case is ±5% of the residual fume loading, and this is about the same percentage of uncertainty that would be expected in the measurements of fuel-air ratios which determined calculated inlet fume loading.

Figure 7 shows a graphical comparison of results from duplicate test runs. The vertical deviation of each data point from the dotted line represents the sum of all deviations associated with operating conditions, sampling, and analytical procedure. It is an over-all measure of the reproducibility of experimental procedures. The vertical difference between the dotted line and the solid line drawn through an average of these points shows that the average deviation is about 20% of the residual fume at all values of collection efficiency. For example, at a collection efficiency of 99.95%, the average deviation is ±0.01%; therefore, collection efficiencies above 99.95% are accurate to within a percentage of ±0.01. At 99% collection efficiency the accuracy is within ±0.2%.

During many of the test runs, samples of effluent scrubber water and of exit gas were taken simultaneously and titrated for boric acid to determine the loading of fume removed by the scrubbing water. For these test runs, percentage collection efficiency was calculated by Expressions (1) and (2) given previously.

Figure 8 shows a comparison of percentage residual fume and percentage collection efficiency by the two methods. The discrepancy of about 20% in percentage residual fume during the earlier work (circular data points) was accounted for by inspection and measurement of the accumulation of boric oxide in the furnace and duct upstream from the first saturating section, and in the ducting and cyclone following the subcooling section. After the burner exit nozzle was installed, thus eliminating a length of air-cooled duct between the furnace and saturating spray, measurement of the accumulation of oxide in the sump ahead of the burner exit nozzle (see Fig. 8) showed that only four percent of the calculated fume from combustion was deposited ahead of the saturating section. This is approximately the extent by which percentage residual fume differed between the two methods of calculation as shown by the dotted line and square data points in Fig. 8.

The use of a refractory-lined combustor that became incandescent during operation and had sufficient volume to give adequate residence time provided


$\frac{A-C}{A}$ x100, Collection Efficiency, per cent of initial loading
99.99 99.98 99.95 99.9 99.8 99.5 99 98 95 90 80 50 0
100 50 20 10 5 2 1 0.5 0.2 0.1 0.05 0.02 0.01
O Tests made before installation of burner exit nozzle
□ Tests made after installation of burner exit nozzle
$\frac{C}{B+C}$ x100, Residual Fume, per cent of initial loading
$\frac{B}{B+C}$ x100, Collection Efficiency, per cent of initial loading
0 50 80 90 95 98 99 99.5 99.8 99.9 99.95 99.98 99.99
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
$\frac{C}{A}$ x100, Residual Fume, per cent of initial loading
A-27192

A=Calulated loading of fume entering scrubber
B=Fume loading removed by scrubber water
C=Residual fume loading in exit gas

Fig. 8. Comparison of two methods for determining percentage residual fume and collection efficiency.

conditions for high combustion efficiency. Therefore, it is believed that errors from incomplete combustion were negligible in the calculation of inlet fume loading.

Several attempts were made to determine the particle size of the fume at the inlet and outlet of the scrubber. Cascade-impactor samples indicated that the particle size of the effluent fume was below one micron. Settling-rate tests in a five-gallon flask indicated that fume particles in the effluent gas were less than 1.6 microns in diameter and that fume particles from the exit of the combustor were of even smaller size. Collection of fume on glass slides revealed particles up to one micron in diameter under an optical microscope.

It is of interest to note that, when collection efficiencies were above 99.8% and exit-gas temperatures were lower than room temperature, there was frequently no visible evidence of fume in the effluent gas.

Results and Discussion

In the study of the capabilities and limitations of the water scrubbing system for the removal of fume, a number of operating conditions were independently varied to determine the effect of each on collection efficiency of the scrubbing system. These variables were saturating water-air ratio, subcooler water-air ratio, mass flow rate of air, fuel-air ratio, hot-gas velocity at which initial precooling and saturation occurred, direction of subcooler nozzles, subcooler-nozzle water pressures, and residence time of the fume between the saturator and the subcooler.

In the early part of the program, effort was directed primarily toward evaluating the operating variables as-

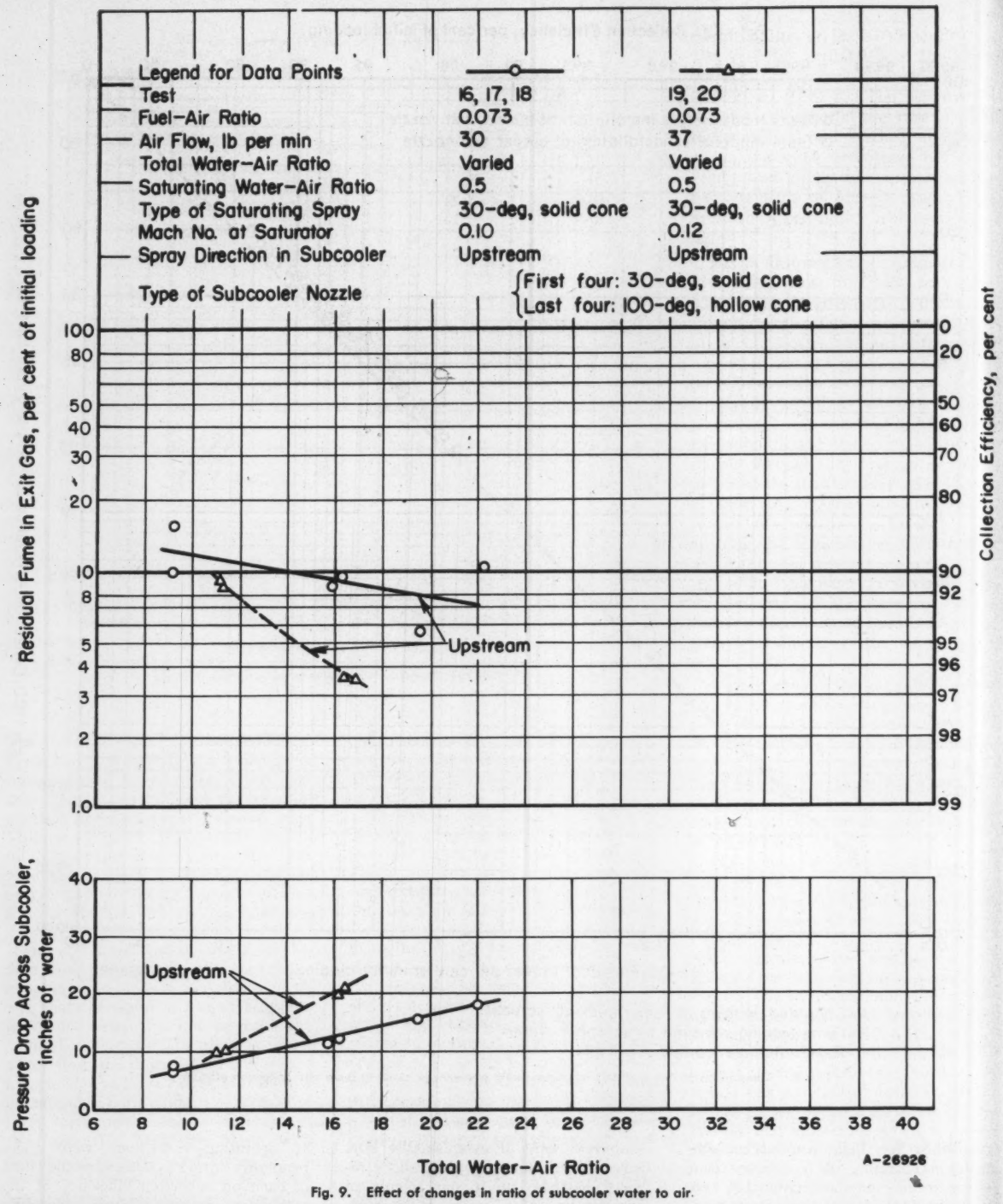


Fig. 9. Effect of changes in ratio of subcooler water to air.

sociated with the subcooler. Collection efficiencies up to 97% were obtained with a configuration of water sprays similar to that already designed for cooling only in the test facility at AEDC. Because this three percent loss would represent considerably more residual fume than the exhausters were expected to tolerate, it was evident that additional improvements were necessary.

Therefore, it was concluded that higher gas velocities of up to Mach 1.0 should be employed at the saturating station. This would be equivalent to spraying the saturating water into the free jet stream of an engine under test.

A complete tabulation of operating conditions and results from all experimental work during the investigation, as well as equipment changes during the course of testing, can be found in the Summary Report[4] for this project.

Effect of Changes in Ratio of Subcooler Water to Air

Figure 9 shows the effect of changes in subcooler water-air ratio for two groups of test runs which were made under conditions shown at the top of the figure. With a fuel-air ratio of about 0.07 and burner exit temperatures at 1600 to 1800°F, 0.5 lb of water per pound of

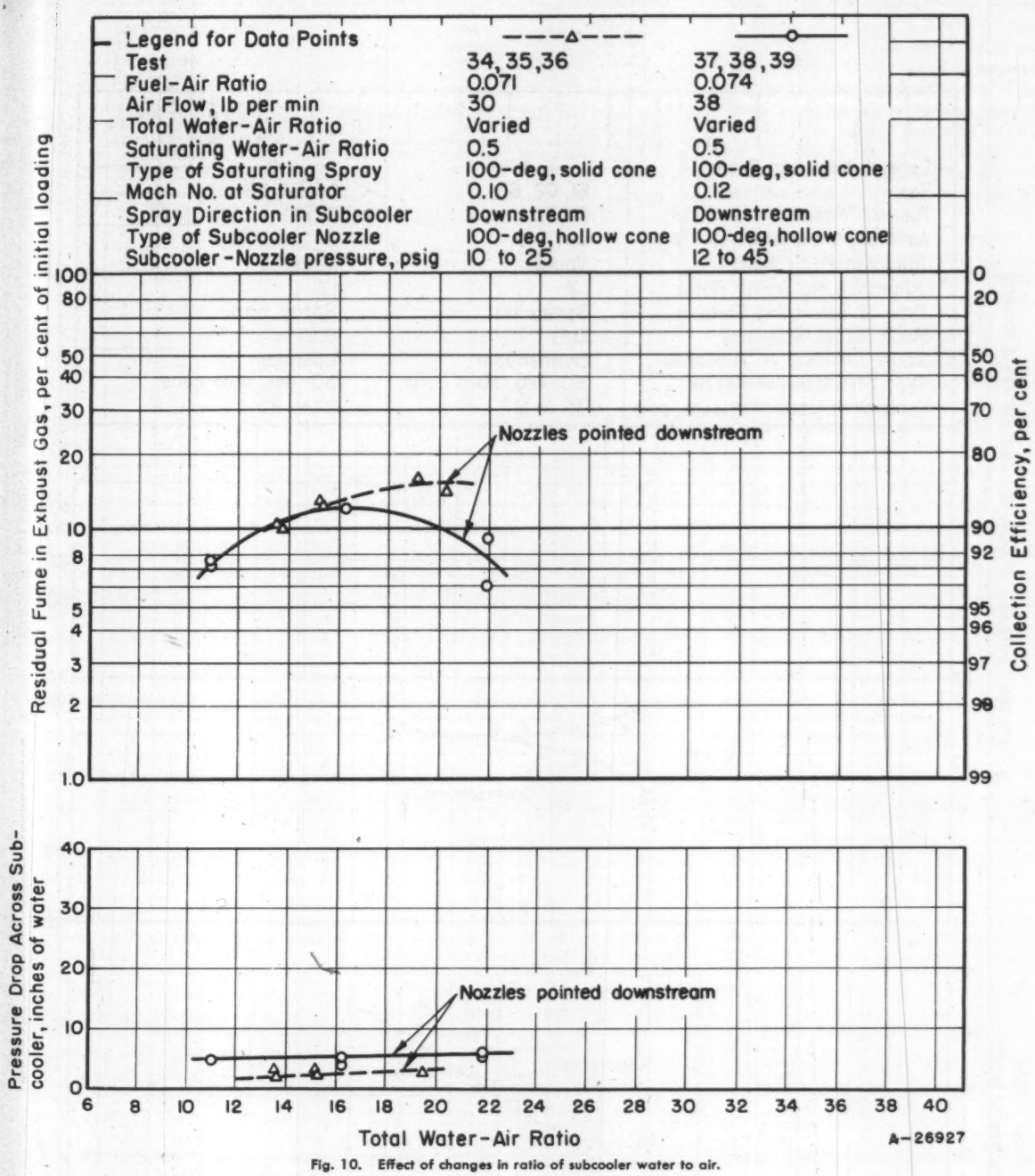


Fig. 10. Effect of changes in ratio of subcooler water to air.

combustion air was sufficient to saturate and cool the gases to about 175°F. In one series of test runs designated by circular data points and the solid-line curve, air rates were maintained at 30 lb per minute and the ratio of subcooling spray water to air was changed to give the total water-air ratios shown on the abscissas of Fig. 9. The other group of test runs was made at increased air rates of 37 lb of air per minute, which gave appreciably lower residual fume content and collection efficiencies up to 96%. These results show that collection efficiency and pressure drop in the subcooler increased with increasing water-air ratios and increasing air rate. The pressure drop shown in Fig. 9 and in subsequent figures does not include the pressure drop across the saturating section, which was about two in. of water at the conditions shown in Fig. 9.

Figures 10 and 11 show the effects of changes in ratio of subcooler water to air at other conditions of operation, as noted at the top of each figure. For the experiments in Fig. 10 with subcooler nozzles pointed downstream, the 100-degree, hollow-cone nozzles were used again because it was felt that the wide angle may be needed in this case to promote full coverage of the subcooler duct. For the remainder of the experiments after Test 40, 30-degree solid-cane nozzles were used.

When the nozzles were pointed upstream in the test runs shown in Figs. 9, 10, and 11, water was supplied to eight nozzles, but when they were pointed downstream, only the first seven nozzles were used because the last nozzle was close to the end of the duct. In all of

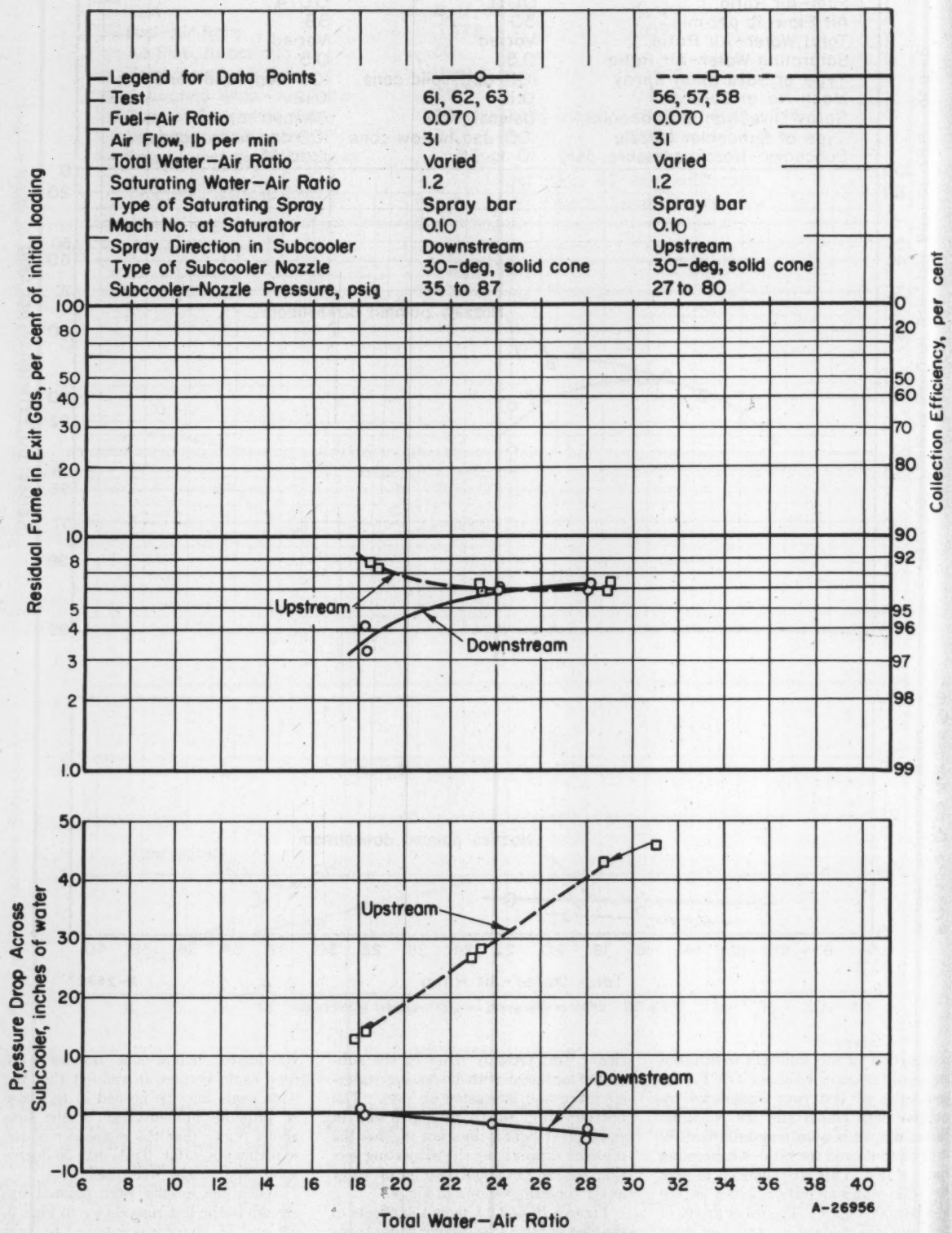


Fig. 11. Effect of changes in ratio of subcooler water to air.

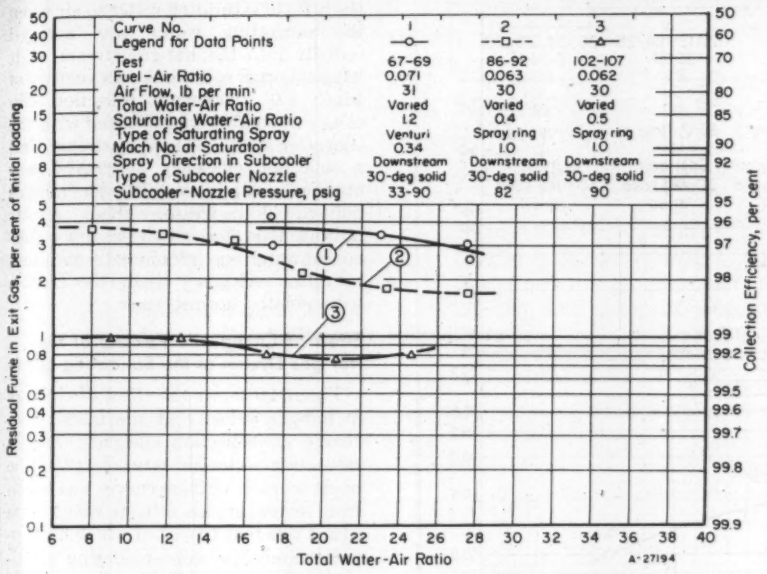


Fig. 12. Effect of changes in the ratio of subcooler water to air.

these test runs, the subcooler-nozzle pressure, and, therefore, the velocity of spray from the nozzle, was dependent upon the flow rate of water. This may account for the initial decrease and subsequent increase in collection efficiency with increasing water rate noted in Figs. 10 and 11 when the nozzles were pointed downstream, because, if inertial impaction existed between fume particles and water droplets, its efficiency would depend on the difference in velocity between the gas stream and the water droplets.

Several trials were made with a venturi which had a throat diameter of $2^1/_2$ in., as described earlier. Hot-gas velocities up to Mach 0.34 were attained at the throat where the saturating water was introduced.

Curve 1 in Fig. 12 was obtained with the venturi, and shows the effect of changing the ratio of subcooler water to air to give total water-air ratios shown on the abscissas of the figure. Changes in the ratio of subcooler water to air were made by changing the flow rate of water in each of the seven operating subcooler nozzles. As a result, subcooler-nozzle pressure increased from 33 to 90 psig as total water-air ratio was increased from 17/1 to 28/1.

After installing the high-velocity nozzle and the spray ring at the burner discharge, as described earlier, a similar series of tests was run in which the ratio of subcooler water to air was varied.

Curves 2 and 3 in Fig. 12 are the results obtained by maintaining constant water rate and constant pressure in each nozzle and increasing water-air ratio by turning on an additional nozzle in progressing to the right along each curve. In Curve 2, the first two nozzles in the subcooler were operating initially to give a total water-to-air ratio of 8/1, and then the third through the seventh, progressively, were turned on. This provided constant residence time for the fume between the saturator and the first subcooler spray for all data points on Curve 2. To obtain Curve 3, the seventh and sixth subcooler nozzles were operating initially, and then the fifth through the first, progressively, were turned on. This decreased the residence time of the fume by a factor of about three to one in progressing to the right along Curve 3. From the difference in the slope of Curves 2 and 3, it appears that increasing the residence time of the fume in the saturated gas stream improved collection efficiency to only a slight extent when saturating water-air ratio was low and hot gas issued from the nozzle at sonic velocity.

Figure 13, Curves 2, 3, and 4, shows the effect of varying the ratio of subcooler water to air on collection efficiency in three different series of test runs in which all conditions were essentially the same except mass flow rate of air. From these experiments, it is evident that an increase in subcooler water-air ratio increases collection efficiency.

Direct comparison of results for operation with subcooler nozzles pointed upstream vs downstream, with all other conditions the same, can be obtained from Fig. 13, Curve 3, and the two data points which are labeled Curve 1. This shows that upstream-pointed nozzles gave an eightfold reduction in residual fume compared with that for downstream-pointed nozzles in the subcooler when hot-gas velocity was Mach 1 and spray-ring water was between 2 and 3 times that needed to cool the gas to saturation temperature. The two triangular data points between Curves 2 and 3 were obtained at the highest airflow rate before the demister screen was installed. When the series of test runs for Curve 4 was repeated with the screen in place, collection efficiency improved at a total water-air ratio of 18, but was not changed at a water-air ratio of 10. All of the test runs shown on Curves 2 and 3 were made without the demister screen or the cyclone separator.

Figure 14 shows additional data on the effect of residence time between saturator and subcooler, and the effect of changes in water pressure in the subcooler nozzles. Over the range of from 14 to 62 psig of nozzle pressure, little change in collection efficiency occurred when the subcooler nozzles were pointed downstream. When pointed upstream, a slight trend toward higher collection

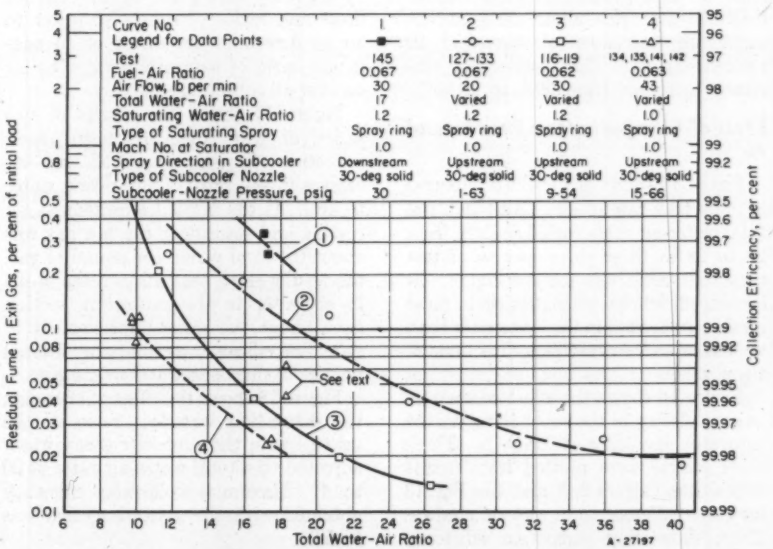


Fig. 13. Effect of changes in the ratio of subcooler water to air.

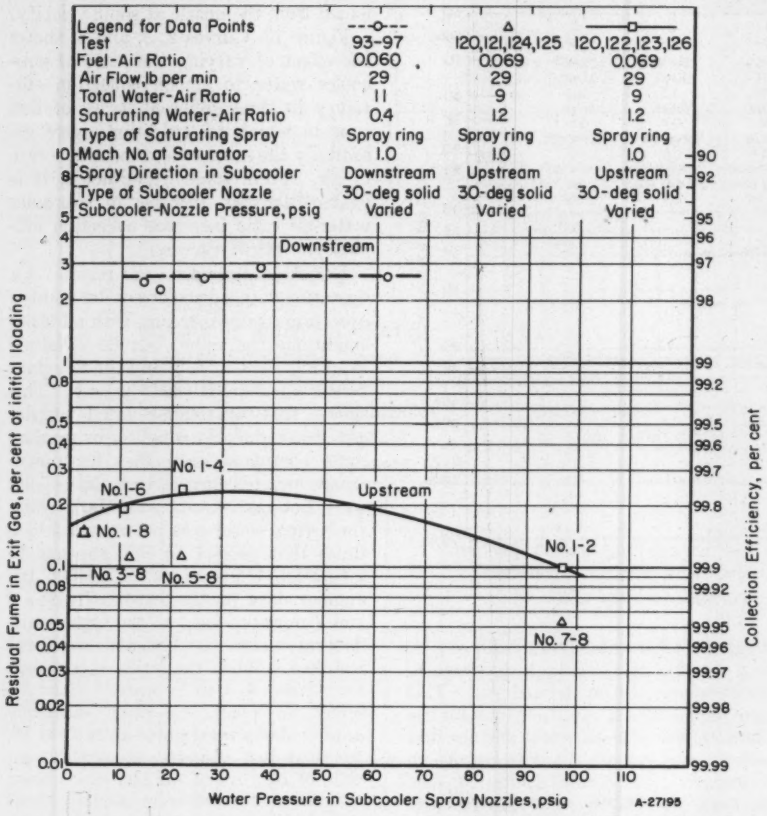


Fig. 14. Effect of changes in the water pressure in the subcooler spray nozzles.

efficiencies was noted for increasing nozzle pressure. The triangular data points directly below the square data points represent conditions of increased fume residence time which were obtained by operating with different subcooler nozzles as shown by the number adjacent to the data points on Fig. 14. Although the increase in residence time was not constant for each of the three pairs of data points, the reduction in residual fume was about 50% at the maximum increases of threefold in residence time. Thus, collection efficiency increased from 99.9 to 99.95%.

Effect of Changes in Mass Flow Rate of Air

Figure 15 shows the effect of changes in mass flow rate of air. Although the total water-air ratio varied slightly from 23 to 28 in these three groups of test runs, the trend was toward higher collection efficiencies with increase in mass air flow (velocity) in the system for both upstream and downstream directions of the nozzles.

Figure 16 shows the effect of changes in gas velocity in the subcooler with the saturator operating at Mach 1. These three curves were plotted from points taken from Curves 2, 3, and 4 in Fig. 13 for three different total water-air ratios. They show that collection efficiency increases appreciably with a twofold increase in mass flow rate of air when the subcooler nozzles are pointed upstream.

Effect of Changes in the Ratio of Saturating Water to Air

In addition to the variables associated with the subcooler, the variables concerning the saturating section were of interest in this study. A number of experiments were made at different air flows and ratios of subcooler water to air to determine the effect of changes in the ratio of saturating water to air on over-all collection efficiency.

Figure 17 shows the results of two series of test runs. In both cases, collection efficiency improved with increases in the ratio of saturating water to air. As the normal requirement for cooling and saturating the hot gas was about 0.4 lb of water per pound of gas, the results show that an increase of 0.6 lb of water in the saturating section gave about the same improvement in collection efficiency as several additional pounds of subcooler water would give.

Figure 18 shows the effect of changing the saturating water-air ratio in the venturi with the subcooler spray water adjusted to a total water-air ratio of 20 to 1. Maximum collection efficiency obtained with the venturi section was 98.5%.

Figure 19 shows the effect of varying the ratio of saturating water to air when the saturating water was sprayed radially into the hot-gas stream as it left the burner exit nozzle at a velocity of Mach 1.0. Maximum collection efficiency of 99.97% was obtained with the subcooler sprays pointed upstream, and a collection efficiency of 99.96% was obtained with the subcooler nozzles pointed downstream. These results indicate that almost twice as much subcooler water was required to maintain collection efficiency when the nozzles were pointed downstream.

Effect of Changes in Velocity of the Hot-gas Stream at the Saturating Spray

Figure 20 shows the effect of changes in hot-gas velocity at the burner discharge on collection efficiency with a saturating water-air ratio of 1:2. The point on each of these curves was taken from several groups of tests which were run at different times but which had approximately the same operating conditions except for Mach number. The marked improvements in collection efficiency as hot-gas velocities were increased to Mach 1 overshadowed the effects of all other variables in this scrubbing system.

Effect of Changes in the Ratio of Fuel to Air

Figure 21 shows the effect of increased fuel-air ratio which resulted in increased fume loading in the combustion gases. Although the range of input fume loading covered by burning a 70–30 mixture of trimethylborate and methanol at fuel-air ratios of from 0.04 to 0.10 is well below that for fuels of high boron content, these results indicate a desirable trend toward higher collection efficiencies for higher loadings. However, the trend is not sufficient to maintain constant weight loading of fume in the exit gases. The dotted curve in Fig. 21 was calculated to show the increase in collection efficiency required to hold a constant exit fume loading of 0.0000033 lb of boric oxide per pound of dry, clean, exhaust gas, or 3.3 ppm by weight. This residual fume loading of 3.3 ppm represents a collection efficiency of 99.98% for the scrubbing process when trimethylborate azeotrope was burned with a fuel-air ratio of 0.07. Residual fume loadings of 3.3 ppm (0.0015 grain per cubic foot) or lower were obtained several times during this experimental work.

Cooling of Exhaust Gases

As it is necessary to cool the combustion products in the test facility to minimize the volume of gas handled by the exhausters, cooling data were correlated in this study. Figure 22 shows the effect of total water-air ratio on temperature difference between inlet cooling water and exit gas for combus-

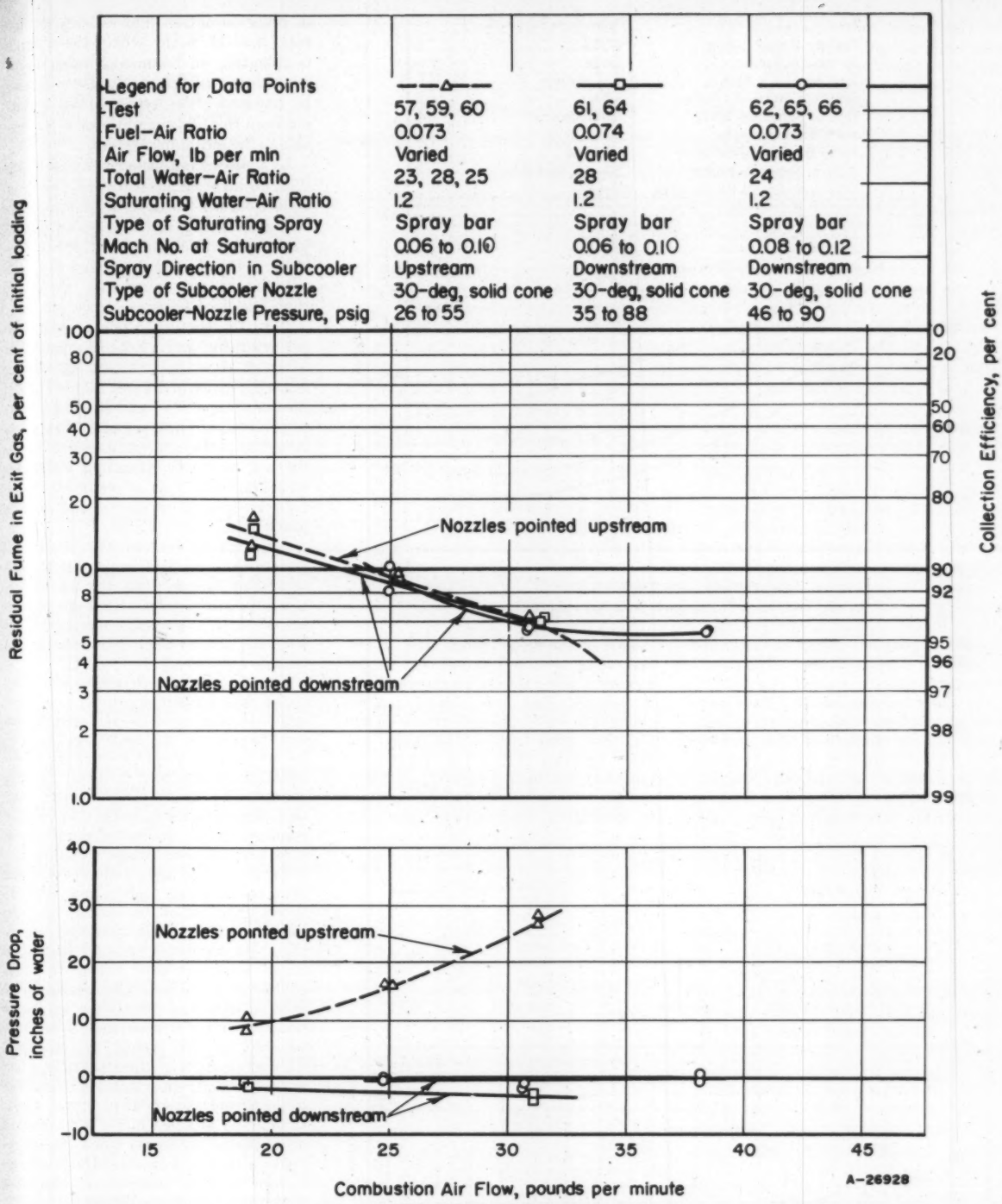


Fig. 15. Effect of changes in mass flow rate of air.

tion air-flow rates of 20, 30, and 40 lb per minute. As the total water-air ratio was increased, the temperature difference between combustion gas and inlet cooling water decreased to about 5°F. The curves also indicate that, at a constant water-air ratio, an increase in combustion-gas flow rate through the subcooler increased the cooling efficiency of the water with the nozzles pointed upstream. This was probably caused by the higher relative velocity between the gas and the water spray droplets. For the same reason, cooling with the nozzles pointed upstream was slightly better than that with the nozzles pointed downstream. At a water-ratio of 30, the temperature difference between inlet cooling water and the exit gas was approximately six to eight °F with the nozzles pointed downstream and approximately four to six °F with the subcooler spray nozzles pointed upstream.

Pressure Drop

Pressure drop through the cooling and cleaning system of a high-altitude test facility is not only a power loss but it also reduces the simulated altitude to

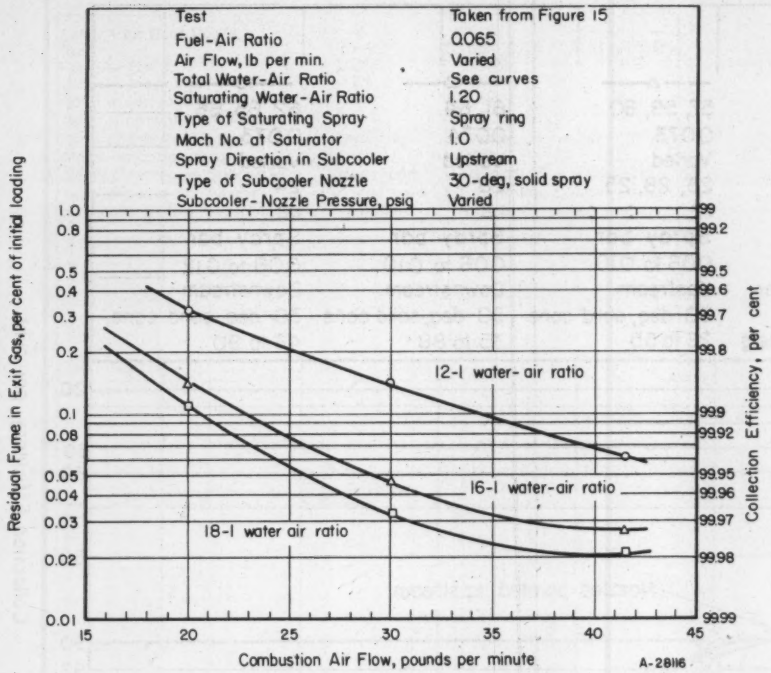


Fig. 16. Effect of changes in mass flow rate of air.

which the engine under test can be subjected. It should, therefore, be held to a minimum.

In the scrubbing system, there were two areas of pressure drop to be considered. The first was the pressure drop in the saturating section from the burner to the entrance of the subcooler. The second pressure drop was that encountered in the subcooler.

Part of the first pressure drop in the saturating section was inherent in the cooling of the exhaust products, and it is believed that this should not be charged to the scrubbing system. During tests with hydrocarbon-fueled engines, approximately 0.4 lb of water per pound of combustion air is injected into the jet stream to cool the exhaust gas to saturation temperature. However, in order to obtain high efficiencies for collection of fume when the engine is operating on boron-containing fuels, saturating water-air ratios up to 1.2 may be required. The pressure loss resulting from this additional water is chargeable to the scrubbing system.

At constant hot-gas velocity of Mach 0.11, an increase in saturating water-air ratio from 0.4 to 1.2 resulted in a pressure drop of three inches and six inches of water, respectively, in the saturating section. The additional pressure drop attributed to scrubbing was, therefore, three inches of water.

With the venturi in operation as the gas saturator, and a hot-gas velocity of Mach 0.34 at the throat, saturating water-air ratios of 0.4 and 1.2 resulted in pressure drops of 16 and 33 in. of water, respectively. Thus, the additional pressure drop in the saturating section due to the use of excess saturating water for scrubbing was 17 in. of water when the hot-gas velocity in the saturator was Mach 0.34.

Although an even greater additional pressure loss would be anticipated in the saturating section from the use of excess saturating water at hot-gas velocities of Mach 1.0, reliable measurements were not obtained for determination of that pressure loss.

The pressure drop across the subcooler was subject to direct measurement and was made to exclude the pressure drop across the centrifugal separator, as this was known for the separator installed at the test facility. In the subcooler, pressure drop varied with total water-air ratio, mass flow rate of combustion air, subcooler nozzle pressure, and subcooler nozzle direction.

Figures 9, 10, and 11 show the effect of total water-air ratio, and Fig. 15 shows the effect of gas velocity on pressure drop at various operating conditions. A maximum pressure drop of 43 in. of water occurred across the subcooler when the subcooler nozzles were pointed upsteam. With the subcooler nozzles pointed downstream, a pressure recovery of six inches was realized. This was caused by the aspirating effect of the subcooler spray nozzles. An additional pressure loss of 49 in. of water was, therefore, sustained in the subcooler at atmospheric pressure when the subcooler nozzles were reversed to point upstream for the purpose of obtaining maximum collection efficiency.

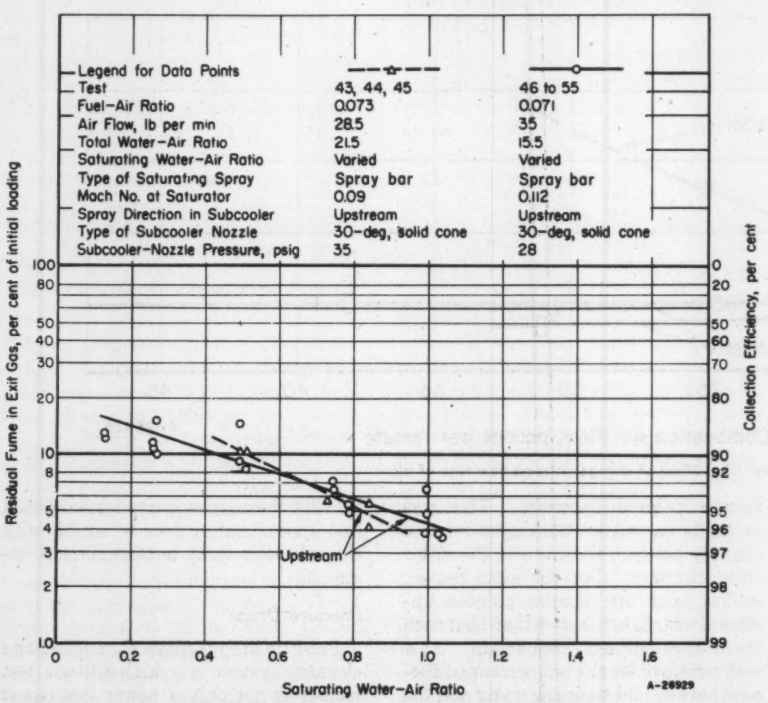


Fig. 17. Effect of changes in ratio of saturating water to air.

Probable Mechanisms of Fume Collection

Several mechanisms for capture of fume by water droplets were considered to account for the marked improvement in collection efficiency which resulted from an increase in hot-gas velocity at the saturating spray. The following mechanisms appeared to contribute in this scrubbing system:

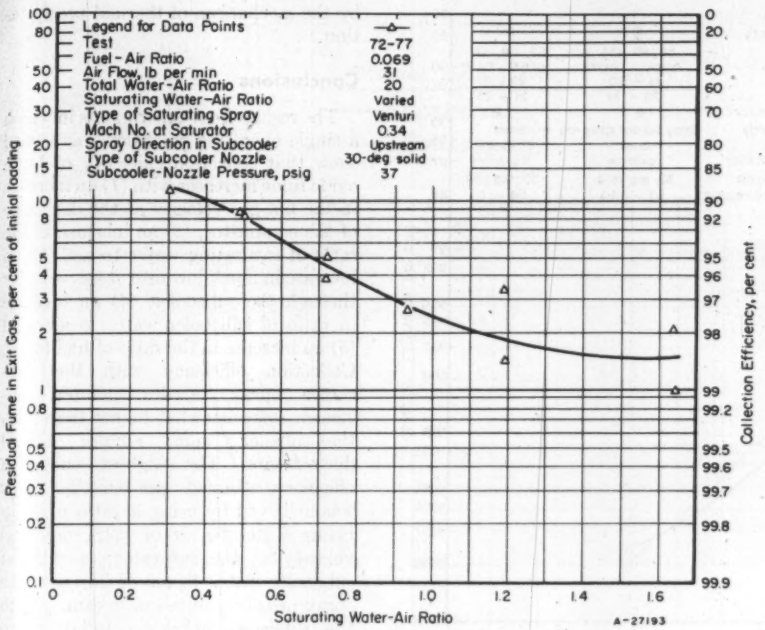

Legend for Data Points
Test 72-77
Fuel-Air Ratio 0.069
Air Flow, lb per min 31
Total Water-Air Ratio 20
Saturating Water-Air Ratio Varied
Type of Saturating Spray Venturi
Mach No. at Saturator 0.34
Spray Direction in Subcooler Upstream
Type of Subcooler Nozzle 30-deg solid
Subcooler-Nozzle Pressure, psig 37
Residual Fume in Exit Gas, per cent of initial loading
Collection Efficiency, per cent
Saturating Water-Air Ratio
A-27193

Fig. 18. Effect of changes in the ratio of saturating water to air.

1 Inertial impaction
2 Diffusion deposition
3 Vapor, or sweep, diffusion
4 Thermal precipitation.

The target efficiency of collection by inertial impaction of fume particles on water droplets in a moving gas stream is a direct function of the following dimensionless group, known as the separation number:[5]

$$\frac{D_p^2 V P_s}{18 \mu D_b}$$

where:

D_p = diameter of fume particle
V = velocity of approach between fume particle and water droplet
P_s = density of particle
μ = viscosity of gas
D_b = diameter of water droplet.

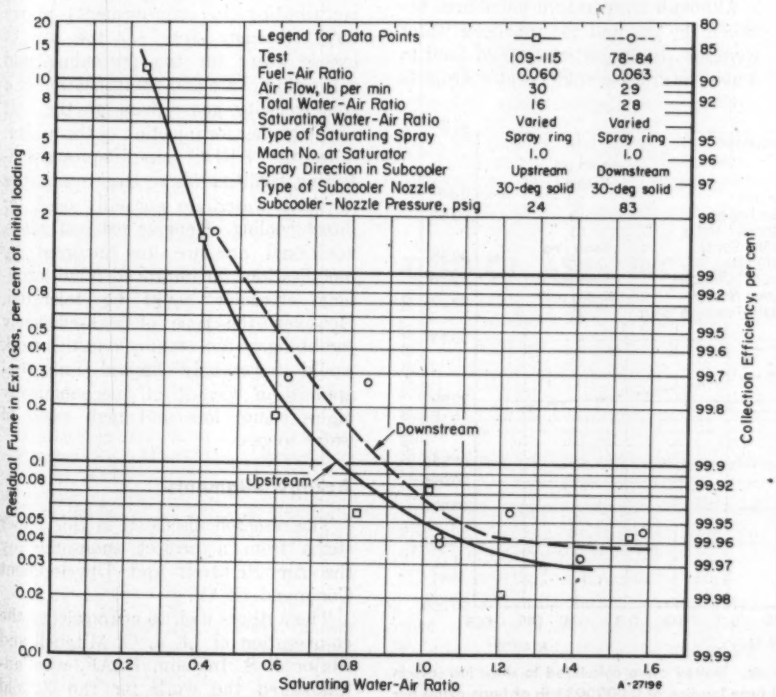

Legend for Data Points
Test 109-115 78-84
Fuel-Air Ratio 0.060 0.063
Air Flow, lb per min 30 29
Total Water-Air Ratio 16 28
Saturating Water-Air Ratio Varied Varied
Type of Saturating Spray Spray ring Spray ring
Mach No. at Saturator 1.0 1.0
Spray Direction in Subcooler Upstream Downstream
Type of Subcooler Nozzle 30-deg solid 30-deg solid
Subcooler-Nozzle Pressure, psig 24 83
Downstream
Upstream
Residual Fume in Exit Gas, per cent of initial loading
Collection Efficiency, per cent
Saturating Water-Air Ratio
A-27196

Fig. 19. Effect of changes in the ratio of saturating water to air.

This indicates that large fume particles, small water droplets, and maximum difference in velocity between fume particle and water droplets promote high target efficiency.

The diffusional target efficiency is given by the following expression:[6]

$$\text{Eff} = 100 \left(\frac{1}{k\sqrt{V D_p D_b}} \right) \text{ percent}$$

where:

V = velocity of approach, fps
D_p = diameter of fume particle, microns
D_b = diameter of water droplet, microns,

and where the value of the constant k depends on the viscosity of the gas. For air it is about 41.

This shows that the velocity of approach and the diameter of fume particle in diffusional deposition have an effect on target efficiency opposite to their effects on inertial impaction for a given size of water droplet.

When small jets of water are sprayed radially into a moving stream of hot gas, the velocity of approach (V) initially equals the velocity of the gas stream. The target efficiency of inertial impaction would initially be at a maximum that varies directly with gas velocity, and would then decrease rapidly as the water droplet accelerates to near gas-stream velocity. An increase in gas velocity would also produce smaller sizes of water droplets. Smaller size water droplets would increase impaction efficiency until some smaller optimum size was reached. Below this optimum size the droplets would accelerate to gas velocity more rapidly, which would reduce impaction due to a decrease in the velocity of approach.

Because of the small size of the fume particles, and the fact that water vapor is being released from the water droplet during the only time when other conditions are favorable for inertial impaction, it appears that inertial impaction does not account for the marked increase in collection efficiency obtained experimentally from increase in hot-gas velocity at the saturator.

From a similar consideration of the submicron sizes of fume and of the decrease in size of water droplets that result from atomization and subsequent evaporation in a high-velocity stream of hot gas, it would appear that diffusional deposition plays an important role in the saturating section.

Although the mechanisms in the saturating section appear to control the scrubbing process by concentrating the fume and water droplets, other mechanisms may predominate for final collection in the subcooler. In addition to

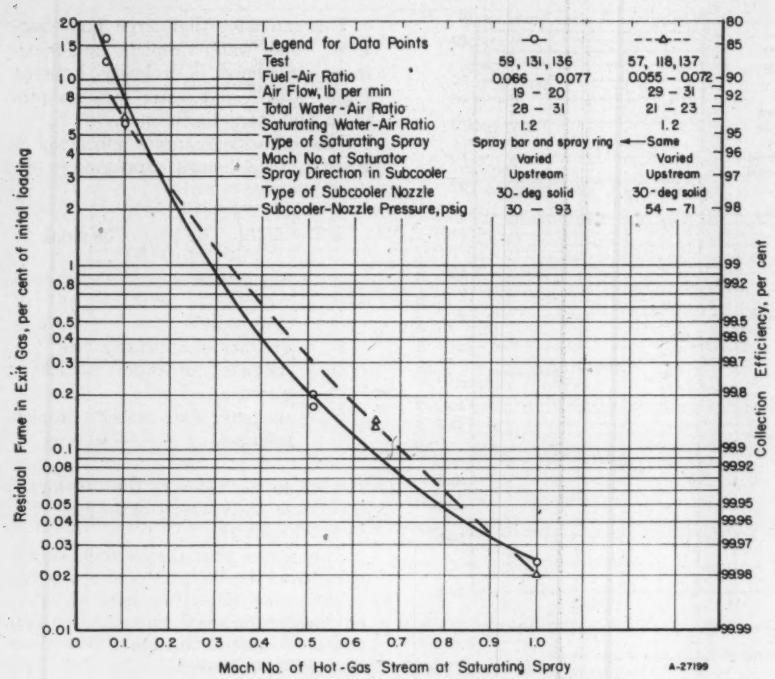


Fig. 20. Effect of changes in hot-gas velocity at the saturating spray.

inertial impaction and diffusional deposition, the large portion of water vapor in the gas stream is believed to be an asset. Enlargement of fume particles which might serve as nuclei for condensation of steam from a supersaturated gas stream in the subcooler would improve inertial impaction but also would have an opposite effect on diffusional deposition. However, the amount of water which would condense on fume particles in the presence of colder water droplets is expected to be negligible in this scrubbing system.

Subsequent condensation on water droplets in the subcooler of the relatively large volume of water vapor generated by evaporative cooling would undoubtedly contribute to the cleaning process. This mechanism is known as vapor, or sweep, diffusion as the diffusion of steam toward the water droplets would sweep fume particles to the water droplets.[7]

Although temperature differences between the gas and the subcooler water were low, fume particles would tend to move toward the colder water droplets by the mechanism of thermal precipitation.

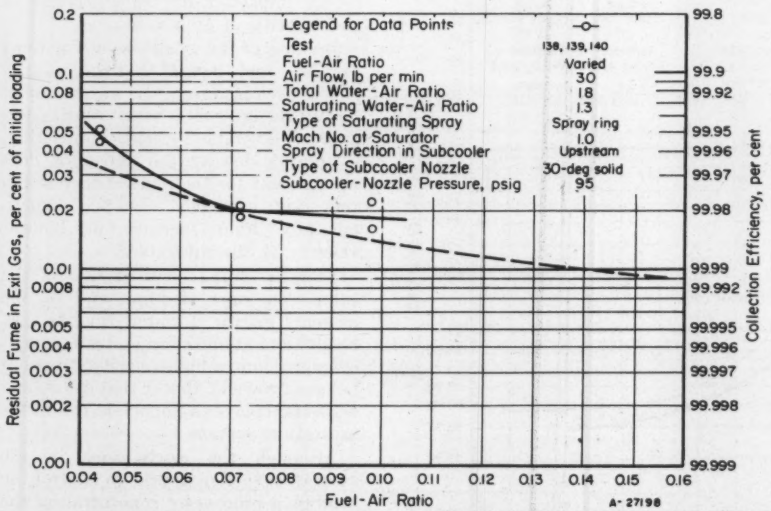


Fig. 21. Effect of changes in the ratio of fuel to air. Dotted curve calculated to show increase in collection efficiency required to hold a constant exit fume loading of 0.0000033 lb of boric oxide per pound of dry, clean exhaust gas.

Conclusions

The results from experiments in which a single operating condition was varied show that collection efficiency of boric oxide fume increases with (*1*) an increase in the hot-gas velocity at the discharge of the combustor, (*2*) an increase in the ratio of saturating water to air, (*3*) an increase in mass flow rate or gas velocity through the subcooler, (*4*) an increase in ratio of subcooler water to air, and (*5*) an increase in the ratio of fuel to air. Collection efficiency with the subcooler spray nozzles pointed upstream was somewhat higher than with the subcooler spray nozzles pointed downstream. The highest collection efficiency attained was 99.98%. This was achieved by using a ratio of saturating water to air of 1.2; sonic gas velocity at the saturator; a ratio of subcooler water to air of 26; and the spray nozzles pointed upstream. With the subcooler nozzles pointed downstream, the highest collection efficiency obtained was 99.96% with a 1.4 ratio of saturating water to air and other conditions approximately the same as above.

Pressure drop across the subcooler increased with (*1*) an increase in water-air ratio and (*2*) an increase in mass flow rate of gas, and reached a maximum of 43 in. of water when the nozzles were pointed upstream. A pressure recovery of up to six in. of water occurred in the subcooler when the nozzles were pointed downstream.

The two most important factors contributing to improvements above 95% efficiency were (*1*) the use of excess water for the precooling and saturating phase and (*2*) utilization of a sonic-velocity gas stream at the exit of the burner for injection of this water.

In the AEDC aircraft-propulsion-testing facilities where large quantities of spray water are normally used for direct cooling of engine exhaust gases, additional pressure loss incurred by modifications for improved fume-scrubbing efficiency could be tolerated. However, the type of high-efficiency scrubbing system employed in this work would have only limited industrial application because of uneconomically high-pressure loss and high ratio of water to gas.

Acknowledgments

The research discussed in this paper stems from a project sponsored by the Air Research and Development Command, USAF.

The authors wish to acknowledge the co-operation of Lt. J. G. Mitchell and Major J. S. Ingham, USAF, who administered the work for the Arnold Engineering Development Center. A. H.

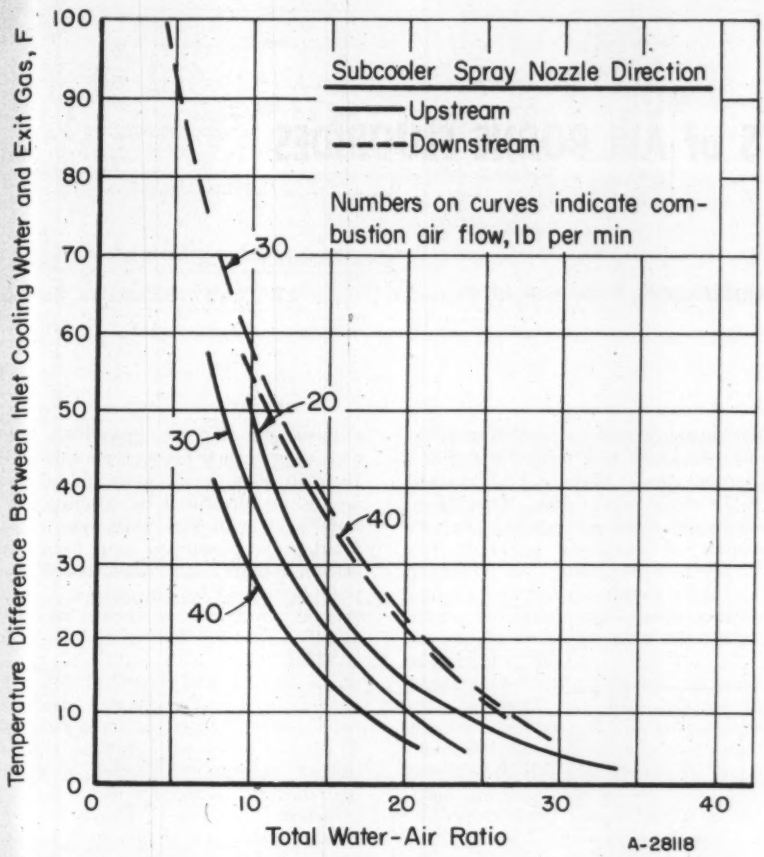


Fig. 22. Effect of total water-air ratio and mass flow rate of air on the cooling of exhaust gases.

Hinners and L. J. David of ARO, Inc., offered valuable assistance as monitors of the work. Prior work on boric oxide fume scrubbing by G. D. Lewis and C. H. King, Jr., of the United Aircraft Corporation was also pertinent in the conduct of this investigation.

The research program was conducted under the direction of R. B. Engdahl, Division Chief, Thermal Engineering Research. Others participating in the study were R. D. Ellsworth, A. Rotkowitz, and I. J. Hess.

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COUNCIL ASKS INCREASE

New emphasis and increased funds for air pollution control programs on both the national and state levels were called for recently by representatives of eight Southern California counties at Ojai.

The Southern California Regional Air Pollution Council recommended that the State appropriate an additional $730,000 for an accelerated program of air pollution research and to expand the statewide air monitoring network.

At the Federal level the Council asked that a White House Conference on Air Pollution be held in the fall to review the most recent advances in air pollution science and to improve and co-ordinate programs at all levels of government.

IGC INSTITUTE MEETS; WILL CONDUCT RESEARCH ON POLLUTION PROBLEMS

Another step was taken in New York on March 3 in the national problem of air pollution control at a meeting of the Industrial Gas Cleaning Institute, Inc., with headquarters at 23 West 45th Street.

The organization is composed of the manufacturers of equipment designed to remove solid and liquid pollutants from the discharge of furnaces, kilns, chemical processes, and other creations of the industrial age. These gas cleaners include electrostatic precipitators, mechanical collectors, fabric filters, and wet scrubbers.

The purposes of the organization are to conduct studies and to do research on methods for improving air pollution control.

Why Institute Was Founded

The Industrial Gas Cleaning Institute, incorporated in 1960 in the State of New York, was founded to further the interests of manufacturers of industrial gas-cleaning equipment, including, but not limited to, mechanical collectors, electrostatic precipitators, fabric collectors, and wet collectors, by encouraging the general improvement of engineering and technical standards in the manufacture, installation, operation, and performance of equipment; devising and improving methods of analyzing industrial gases; disseminating information on air pollution; the effect of industrial gas cleaning on public health; and general economic, social, scientific, technical, and governmental matters affecting the industry, together with the views of the members thereon.

Air Pollution Costly

Air pollution is said to cost this nation 13 billion dollars annually in cleaning bills, health, and corrosion.

At the first annual meeting in the Roosevelt Hotel, John T. Doyle vice-president of the Aerotec Industries, Greenwich, Connecticut, was elected president; L. I. Andrus, vice-president of Wheelabrator Corporation, Mishawaka, Indiana, and John Liskow, American Air Filter Company, Louisville, Kentucky, manager of industrial sales, secretary aud treasurer.

Directors named were: Donald L. DeVries, Baltimore, Maryland; Robert Kopita, New York; Robert R. Leach, Mineola, New York; Kenneth J. Mackey, St. Paul, Minnesota; William W. Moore, Bound Brook, New Jersey; Hugh Mullen, New York; Robert S. Stewart, Los Angeles, California; and W. O. Vedder, Hagerstown, Maryland.

DISPERSION *and* EFFECTS *of* AIR BORNE FLUORIDES *in Central Florida**

E. R. HENDRICKSON, Ph.D., Research Professor, University of Florida, Gainesville, Florida

In an area centered on the community of Bartow, Florida and having a radius of approximately 25 miles is located one of the more important mineral industries of the world. Few people outside of the industry appreciate the importance of Florida phosphate rock to the state, to the nation, and to the world. From this 500 square mile area just east of Tampa comes 75% of the nation's and about 1/3 of the world's supply of phosphate rock. Mining of the pebble phosphate rock began on a relatively small scale in 1890 and at the present time exceeds 10 million long tons a year. These deposits were laid down approximately 10 to 15 million years ago and are now found in strata varying from five to 20 feet in thickness. Deposits which are being mined at the present time contain 66 to 80% of tricalcium phosphate.

Mining is accomplished by open pit methods using huge electric draglines of caterpillar or walking type with bucket capacities of 10 to 20 cu yds. The pebble phosphate, as mined, is mixed with varying quantities of clay and sand and must be cleaned before further utilization. For many years this was strictly a mining operation. The mined material was usually washed, then dried and ground, if necessary, before shipping elsewhere for processing. The rock as mined is essentially a fluorapatite having the formula $Ca_{10}(PO_4)_6F_2$ or for the purpose of our discussion can be more conveniently written as $3Ca_3(PO_4)_2 \cdot CaF_2$. The tricalcium phosphate is only slightly soluble and when combined with the calcium fluoride is nearly completely insoluble in water. The fluoride represents approximately four percent by weight of the total compound. In order to make the phosphate available to plants or animals and at the same time nontoxic, the fluoride must be removed.

For economic reasons processing of the raw phosphate rock to usable fertilizer components was begun in Florida about 1947. Since that time 10 different companies have inaugurated the production of phosphatic materials from the raw rock phosphate. At the present time there are nine drying and grinding plants, three superphosphate plants, eight triple superphosphate plants, one defluorinating plant, and two installations for the production of elemental phosphorus. All but two of these installations are located in a concentrated area of approximately 100 square miles. Unfortunately this same general area for years has been used for raising cattle, citrus, winter truck crops, and gladiolus for cut flowers.

The release of fluorides from the phosphate rock is usually accomplished by treatment with heat or acid. The latter is most common in Florida. Superphosphate, which provides approximately 15 % available phosphorus, is produced by sulfuric acid treatment of the phosphate rock according to the following theoretical reaction:

$$Ca_3(PO_4)_2 + 2H_2SO_4 + H_2O \rightarrow 2CaSO_4 + CaH_4(PO_4)_2 \cdot H_2O$$

This results in formation of the more soluble mono-calcium phosphate. The demand for higher quantities of available phosphorus was met by the production of triple superphosphate which contains approximately 45% available phosphorus and is produced by the following theoretical reactions:

$$2Ca_3(PO_4)_2 + 6H_2SO_4 + 12H_2O \rightarrow 4H_3PO_4 + 6CaSO_4 \cdot 2H_2O$$

$$Ca_3(PO_4)_2 + 4H_3PO_4 + 3H_2O \rightarrow 3CaH_4(PO_4)_2 \cdot H_2O$$

In the two installations located in Florida, elemental phosphorus is produced in an electro-thermal furnace by combining the rock with quantities of silica and coke and vaporizing the phosphorus and other components of the mix.

In applying the theoretical consideration to actual plant production, a number of different procedures are used to produce triple superphosphate.[11] In nearly all of the processes, phosphoric acid is manufactured by reacting sulfuric acid with the phosphate rock, filtering the phosphoric acid from the calcium sulfate, and concentrating the phosphoric acid by evaporation. This general procedure is shown on the attached sketch. The phosphoric acid is then reacted with additional phosphate rock by one of several different procedures. In Florida the processes most generally used conform roughly to the run of the pile, granular chemical, or Meyers wet process of triple manufacture. These are shown on the attached sketches. Where diammonium-phosphate is produced it may be accomplished as shown. Elemental phosphorus production by the electrothermal furnace method is also shown in the sketch.

Unfortunately, at the same time the sulfuric and phosphoric acid are reacting with the tri-calcium phosphate, they are also reacting with the calcium fluoride present in the phosphate rock. According to Semrau,[9] silicon tetrafluoride is formed during the process as indicated by the following reaction:

$$CaF_2 + H_2SO_4 \rightarrow CaSO_4 + 2HF$$
$$4HF + SiO_2 \rightarrow SiF_4 + 2H_2O$$
$$6HF + SiO_2 \rightarrow H_2SiF_6 + 2H_2O$$
$$3SiF_4 + 2H_2O \rightarrow 2H_2SiF_6 + SiO_2$$
$$H_2SiF_6 \rightarrow SiF_4 + 2HF$$

The reaction of the acid with calcium fluoride produces hydrofluoric acid which subsequently reacts with the silicon dioxide in the phosphate rock. Fluosilicic acid is claimed not to exist as such in the vapor state and decomposes to form more silicon tetrafluoride and hydrogen fluoride. According to more recent work by Fox and Hill[3] the fluoride is not released as hydrofluoric acid to later combine with silica, but is released directly from the acid medium as silicon tetrafluoride. It seems apparent, however, that the fluoride emission at least from the manufacture of triple superphosphate consists of HF, SiF_4, and H_2SiF_6 in combination.

* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

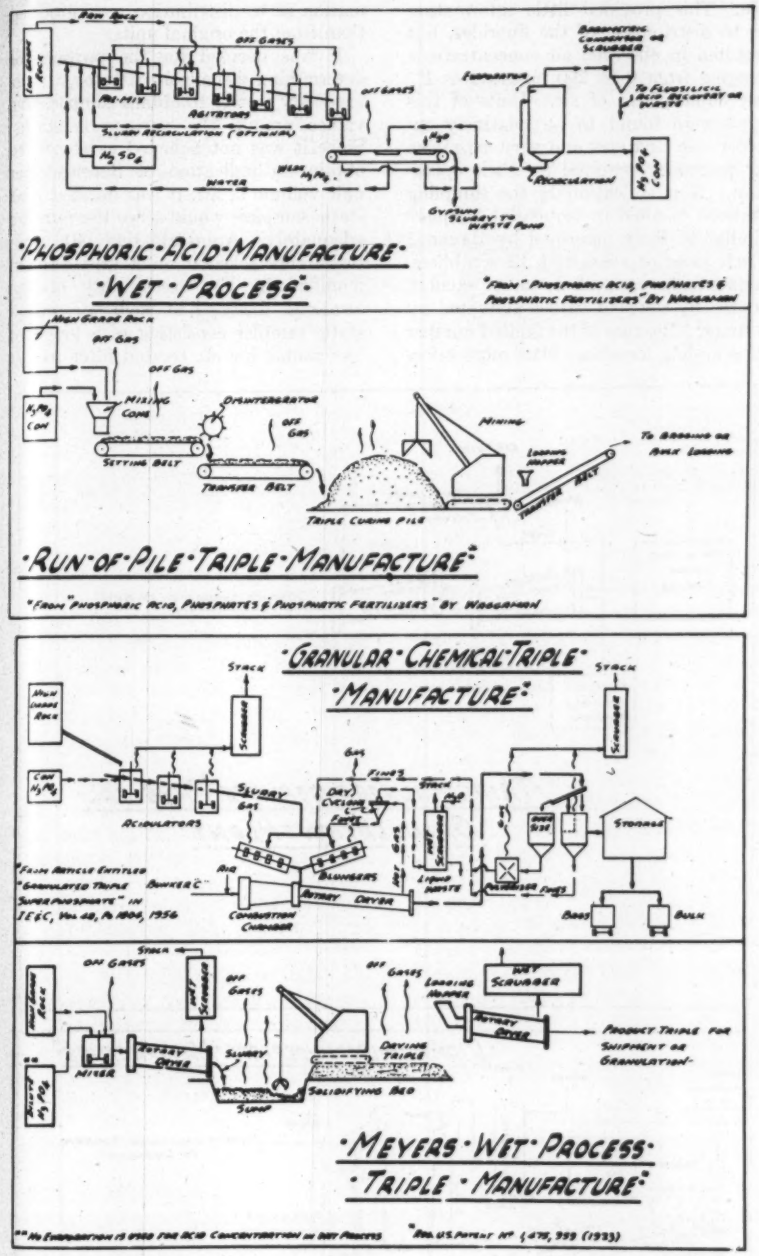

Fig. 1.

Semrau also states that the fluoride offgases from the manufacture of superphosphate are essentially in the form of silicon tetrafluoride, and from heat-defluorinated rock in the form of hydrogen fluoride. In addition to the gases and vapors released from some of the chemical processes essentially insoluble dust containing approximately four percent fluoride may be discharged from drying and grinding operations.

Fluorides in gaseous form particularly when present as HF, SiF_4, or H_2SiF_6 are highly toxic to growing vegetation, to humans, and to animals when present in sufficient concentration. In the area under discussion citrus groves, winter truck crops, and commercial gladiolus all show evidence of damage by air-borne gaseous fluorides. Fluorosis in cattle is alleged as a result of ingestion of forage contaminated by gaseous and particulate fluorides. It has been estimated that as much as eight tons of gaseous fluoride per day may be discharged into the atmosphere in this area of Florida. Most of the manufacturers involved are making rapid strides toward bringing their fluoride emissions under further control.

Vegetation Damage

Practically all vegetation of any commercial consequence is subject to damage by exposure to some of the more active forms of gaseous fluorides at levels far below one part per million by volume. It has been reported that the most sensitive form of plant life is the gladiolus which reportedly will burn when exposed for a few days to as little as three parts per billion by volume.[10] Commercial growing of gladiolus for cut flowers is a multimillion dollar industry in Florida. Unfortunately many of the places most suitable for gladiolus culture are within the area of influence of air-borne fluorides from phosphate processing. Gladioli apparently suffer no visible effect from fluoride fumigation until the leaf level reaches about 30 ppm on a dry weight basis. Above this level, depending on the species, several symptoms of fluoride toxicity may be noted.[2] Analysis of leaves in the growing area of Florida has indicated levels in excess of 175 ppm.

A part of the west coast located south of Tampa along Tampa Bay has long been known as "The Salad Bowl." Winter truck crops such as tomatoes, lettuce, corn, endive, cabbage, and other vegetables have been produced in this area. Although vegetation of this type is more resistant to fluoride damage, the area is located closer to a potential source of fluoride. Damage to many of these winter truck crops from fluoride air pollution has been alleged.

Possibly the leading agricultural industry on the Florida peninsula involves the raising and processing of citrus. Unfortunately, heavy concentrations of citrus groves are found in Polk and Hillsborough County within a relatively short distance of the phosphate producing area. Citrus damage which has been attributed to gaseous fluorides includes defoliation of trees, reduction of yield, reduction of growth, leaf burn, and severe chlorosis. The latter condition has been noted in the Lakeland-Highlands area, in the Bartow area, and in east Hillsborough County. The chlorotic pattern is similar to but not identical with that resulting from boron toxicity.[12] The damage can generally be differentiated from boron toxicity by analysis for fluorides and observation of a lack of "gum" on the underside of the leaf. Such analyses have revealed a fluoride content in chlorotic leaf of 300 to 350 ppm whereas normal appearing leaves, 30 miles outside the affected area, contain 10 to 30 ppm.

Damage to Domestic Animals

Domestic animals such as cattle are grown in large numbers in Polk County. In recent years fluorosis in certain

herds has been diagnosed by qualified veterinarians. Among the domestic animals, cattle are probably the most susceptible to fluoride toxicity, and horses appear to be quite resistant. In recent months certain veterinarians in the affected area have diagnosed fluoride toxicity in the horse population.

Acute fluoride poisoning rarely occurs in livestock in this area. Most of the severe cases noted are the results of chronic poisoning. Up to a certain level fluorides are excreted, and only if this intake level is exceeded is the material deposited in the bones. Teeth in the process of formation are easily affected by fluorides. Teeth which have erupted prior to the time an animal was exposed to a contaminated pasture may show some mottling and softening. Usually, however, any tooth damage which occurs in the animals indicates that the animal was raised in a herd which was fed on contaminated forage. Skeletal defects may be noted by the presence of a bony over-growth or exostosis on the bones of the leg, the jaw, and the ribs. Lameness may occur as a result of the over-growth and may progress to the extent that it is impossible for the animal to lie down if standing or get up if lying down. Adult males affected with fluorosis will inevitably exhibit a lack of appetite, emaciation, and general ill health due to malnutrition. Milk production and reproduction may be affected.

The mode of entry of fluorides into the animal is not through the respiratory system but through the digestive system. Cattle develop fluorosis by feeding on pastures contaminated by fluorides. Soluble fluorides are reportedly two times as toxic as the same amount of insoluble fluorides. In the area under discussion forage may be contaminated with phosphate rock dust or with gaseous fluorides. The fluoride level in forage which is detrimental to beef cattle on a continuous diet of the contaminated material is reportedly 30 to 50 ppm if the fluoride is in soluble form.[14] Pasture grasses in the immediate vicinity of phosphate processing plants reportedly exceed this amount during some seasons.

Effect on Human Health

Extensive medical and dental surveys during the past three years have failed to reveal any human defects attributable to fluorides.

Survey

In order to determine the distribution of gaseous fluorides in the Polk County area, the University of Florida Air Pollution Research Laboratory undertook an investigation several years ago. Initially six dynamic sampling stations were established in the area and operated on a variable time schedule. This provided little information as to distribution of the fluorides, but resulted in observed air concentrations ranging from 0 to 200 micrograms F^- per cubic meter of air. Units of this type were found to be relatively expensive in first cost and very expensive in manpower required for their operation. A modification of the sampling stations resulted in sequential samplers similar to those described by Raynor.[7] Each sampler contained 12 scrubbers, sequentially connected to a vacuum source by solenoid valves activated by a timer. Because of the limited number of sampling locations, little more information as to distribution was obtained than from the original units.

It was decided for the purpose of determining dispersion patterns, it was necessary merely to obtain comparative values among the various locations. Since it was not believed necessary to obtain an indication of fluorides per unit volume of air, it was decided that static samplers would serve the purpose adequately. Approximately 40 locations were selected on a grid pattern modified by the accessibility of the location. Located at each site was a static sampler consisting of a louvered box containing six treated filter papers

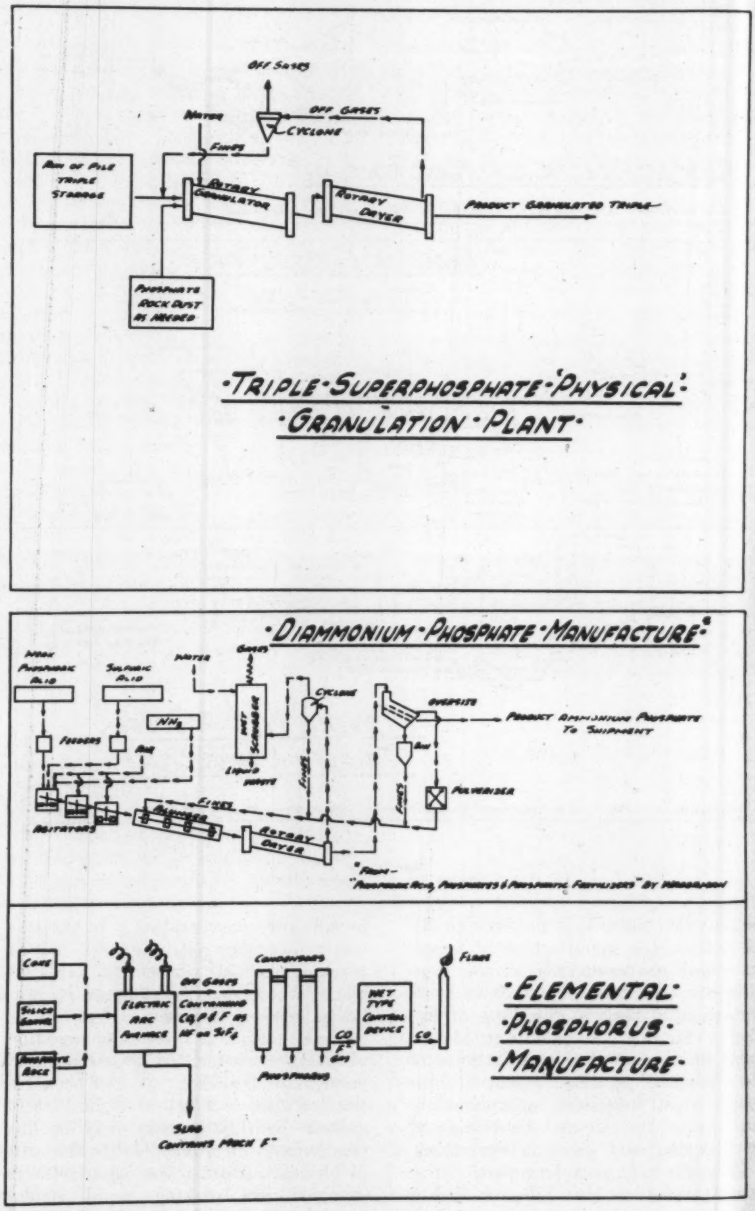

Fig 2.

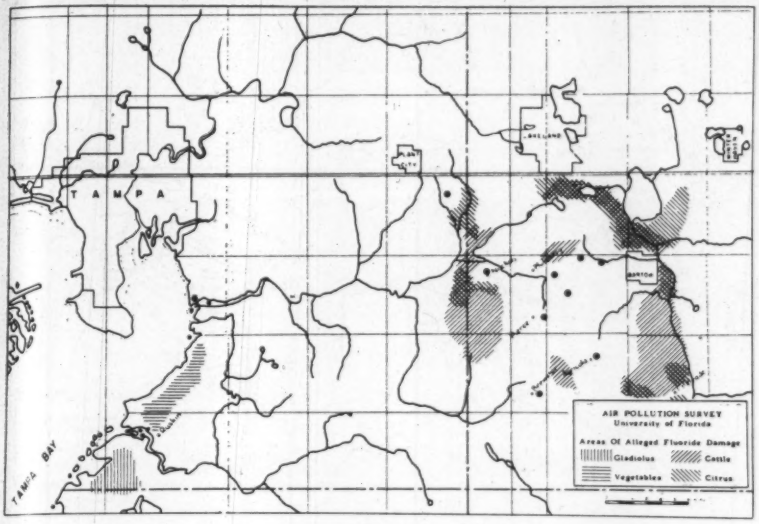

Fig. 3.

and a lead peroxide candle. The Florida State Board of Health located about 50 additional stations containing only fluoride units. The filter paper technique for fluorides and the lead peroxide procedure for sulfur dioxide have been described by a number of workers.[1, 4, 6, 8, 13]

The static fluoride sampling technique usually uses filter papers dipped in a lime slurry. Because of the insolubility of the lime at the concentrations used, a heavy deposit is left on the filter papers. Under certain conditions the lime may flake or dust off and if the paper has been exposed, fluorides may be lost. In order to take advantage of the benefits of a calcium salt while at the same time using one which is more soluble, this laboratory treats the filter papers with calcium formate solution. The solution is prepared by adding 100 grams of calcium formate to a liter of water and stirring to put the powder in solution. 11.0 centimeter circles of Whatman No. 2 filter paper are dipped into the solution and hung up to dry in an atmosphere free of fluorides. Papers are usually identified by marking a number in pencil prior to the dipping operation. Before dipping, each box of paper is punched so that a $^1/_4$-in. hole appears in the center of each sheet. Racks for mounting the six sheets of paper are made of pieces of $^1/_4$-in. PVC rod about seven inches long. A plastic washer $^1/_2$-in. O.D. is cemented to one end of the rod and the other end is threaded for a distance of $1^1/_2$-in. Six spacers one-in. in length are cut from PVC pipe $^5/_{16}$-in. I.D. and $^1/_2$-in. O.D. Papers and spacers are alternated on the rod and the assembly compressed by turning a bronze nut on the threaded end. After the papers have dried they are assembled on the racks and stored in a footlocker in an area free of fluorides.

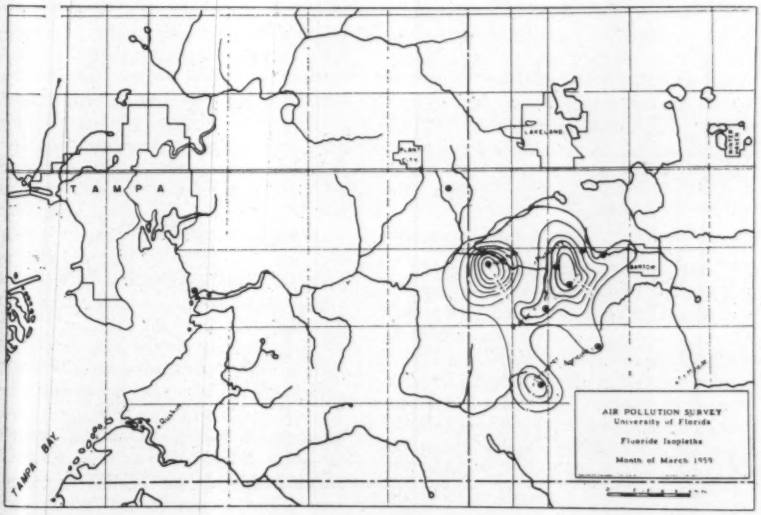

Fig. 4.

The lead peroxide units are prepared by a procedure modified slightly from that suggested by Wilsdon and McConnell.[13] A glass speciman jar 4.4 centimeters in diameter and 15 centimeters in length is used as the form. These jars are closed with Bakelite screw caps and are commonly known as "Olive jar—5 oz." It is essential that preparation and storage of the materials take place in a location which is not exposed to sulfur dioxide or sulfates. Each jar should be numbered near the cap end with a scriber. Each jar should be marked with a scriber at a distance from the closed end such that the total area below the mark including the bottom surface is equal to 100 square centimeters. For the jar recommended, this distance is 6.1 centimeters. Pieces of 2.5-centimeter (flattened diameter) tubular gauze are cut about 20 centimeters in length and stapled through the gauze perpendicular to the long axis about 0.5 centimeter from one end. The gauze is turned inside out and slipped smoothly over the closed end of the jar. The top edge should be even with the scribed mark. A mucilage is prepared by dispersing two grams of gum tragacanth in 10 milliliters of absolute ethanol and adding with one action, while stirring, 190 milliliters of distilled water. A thin smooth paste is prepared by mixing the lead salt and mucilage in the ratio of about seven grams of lead dioxide to five milliliters of mucilage. The paste must be mixed thoroughly at frequent intervals. If the mixture becomes too thick, additional five percent ethanol in distilled water may be added to balance the solvent losses. The prepared forms are dipped to the scribed mark with the gauze serving as a reinforcement. After dipping they are allowed to drain for a few seconds and the surface smoothed with a one-inch brush. The cylinder is dried slowly in air.

A completed cylinder should have a reactive surface of 100 square centimeters. The coating should be thick enough to hide the texture of the gauze but thin enough to dry without crazing. The consistency of the paste and method of application may be varied to produce the desired results as experience dictates. At least one prepared cylinder should be stored in an air-tight jar for use as a control when the anlysis is run. All cylinders which are to be exposed simultaneously should be prepared at the same time.

Both the sulfur dioxide unit and the fluoride unit are exposed in a louvered shelter which provides adequate air flow but protects the units from rain. The lead peroxide cylinder is screwed

into a cap attached to the top of the shelter. The fluoride unit is turned into a threaded holder in the shelter top. After exposure for one month, all units are replaced and the exposed ones returned to the laboratory for analysis.

Fluorides are determined by ashing the exposed filter papers and distilling from sulfuric acid. The distillate is analyzed for fluorides by the colorimetric method described by Megregian[5] using zirconium chloride and Eriochrome Cyanine-R. Following comparison in a Beckman Model B spectrophotometer the fluoride concentration is determined from a previously prepared standard curve. Results are expressed in units of micrograms per square centimeter of exposed surface.

Sulfates are determined gravimetrically after precipitation with barium chloride. Results of observations are reported as micrograms of sulfate per 100 square centimeters. The results of sulfur dioxide measurements are not reported at this time.

During the sampling period, continuous records were obtained of the wind direction and velocity at three different locations in the area and of the vertical temperature gradient at one location. Four recording rainfall stations were in operation.

When the analysis is complete, concentrations are plotted on maps for each month at each sampling location. From this information isopleths are drawn in the light of the wind roses for that particular month. Monthly fluoride isopleths for the quarter points of the year 1959 are presented on the attached maps.

Information concerning areas of alleged fluoride damage was obtained mainly by interview. Preliminary advice was received from county agents who have intimate knowledge of conditions in the area. Interviews were then arranged with ranchers, grove owners, vegetable growers, flower growers, and others who had reasonably valid complaints of damage which they felt was due to fluoride fumigation. Confirmation of complaints was obtained from county health department personnel, dentists, physicians, veterinarians, and specialists from the various state agricultural experiment stations. In most cases the latter group of persons had scientific justification of fluoride damage in the form of clinical records, analyses, or experimental evidence. General areas of alleged fluoride damage in four categories are shown in Fig. 3. It should be pointed out that much of the land within the Mulberry-Bartow-Brewster triangle is not used for agricultural pursuits on a commercial basis. Because of financial limitations, the air quality survey was not extended to the source southeast of Tampa and southeast of Plant City.

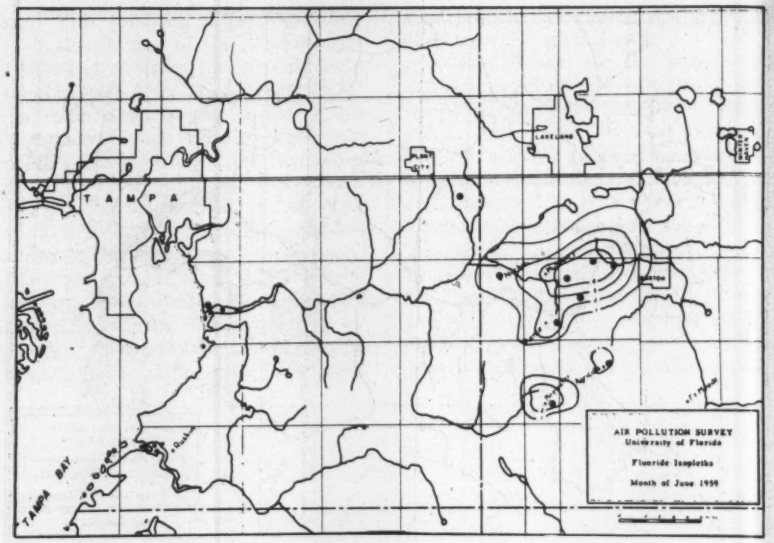

Fig. 5.

Discussion

Monthly maps showing fluoride isopleths are available for each month of 1959 and for each month of the first quarter of 1960. In the interest of saving space, only the maps for the months of March, June, September, and December of 1959 are presented here. These maps are seasonally characteristic of the entire year. As might be expected, a considerable variation is noted in the monthly concentration patterns and some variation in the general over-all pattern. Highest concentrations have been found to occur in the fall and winter months. This is the time when forage grass collections also show the highest fluoride level. On the basis of one year's data, no significance is attached to this variation.

These plots do, however, show general trends in the area. From the four maps presented here, information can be deduced concerning the extent of the heavily polluted area, the contribution of several sources to one area, the effect of plant shutdown, the possible effect of seasonal production, and the possible effect of seasonal weather patterns.

The maps for each month show the relative exposure of ground level stations to fluoride contamination. Within the area of the highest exposure practically no agricultural activity is encountered. From the information reported by agricultural interests, it appears that areas exposed to relative

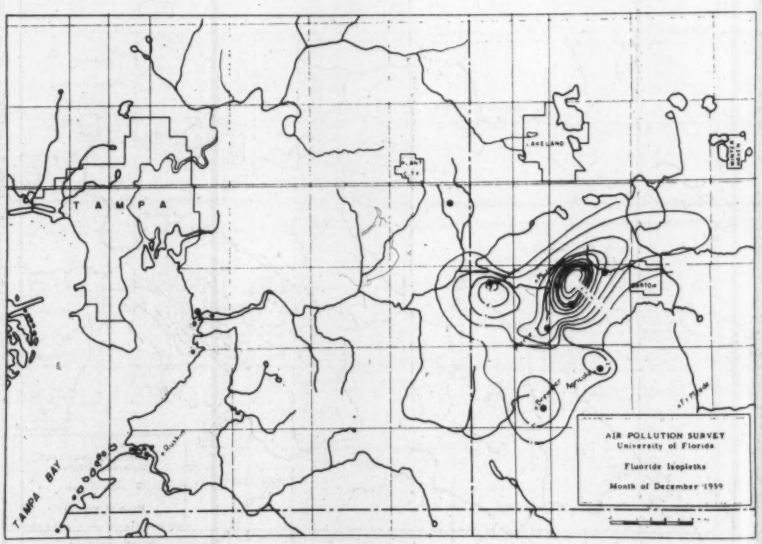

Fig. 6.

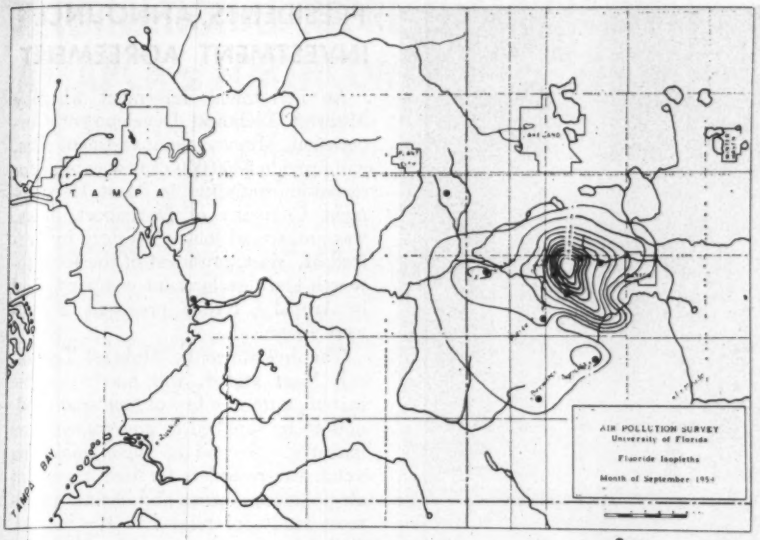

Fig. 7.

concentrations of one or two experience difficulty with citrus and cattle. If the map of alleged damage is compared with the maps of fluoride isopleths, it will be noted that some damage areas are exposed to relative concentrations of as high as four the year round, whereas others are exposed to such levels infrequently, if at all. Although no isopleth is plotted for relative concentrations below one, in practically all instances a level of 0.5 is reached within three miles of the one isopleth.

The highest fluoride levels reached during the year occur roughly one-half way between the towns of Mulberry and Bartow. It is generally true that this is the "hottest" spot in the entire area. It should be noted that three sources are in the immediate vicinity of this high spot, and three other sources are within close proximity. During parts of the year the contributions from these sources combine to produce a relative exposure level of as high as 13. Fortunately no commercial agricultural activities are operating in this area. One experimental orange grove is located close to the area but results of this operation are not available.

In the month of March a high level was noted in the vicinity of the town of Nichols. This peak disappears on the June map, recovers slightly on the September map, and returns to nearly its previous level on the December map. This potential source consists of several different phosphate operations. In April the plant went on strike and was struck until August of 1959. The results appear rather graphically on these four maps. Reference to the June map indicates a low level of relative fluoride exposure throughout the entire area. The exact cause of this is not known, but several explanations might be offered. During the summer months extremely unstable conditions occur in the air over Florida. Ventilation is good and during the day effluents are seen to rise vertically. Furthermore this is a time when many of the phosphate operations are at a low level of production. In December on the other hand, phosphate production is at a high level and several meteorological conditions are conducive to ground level fumigation. The incidence of low level inversions is greater than at any other time of the year, and cold fronts moving across the state tend to dump damaging gases as the front passes.

The limitations of collecting exposure data by these methods and of presenting the data in this manner are recognized. It is felt, however, that the simplified techniques using static samplers fulfill the requirements of this particular type of survey. The technique enables determination to be made of the extent of pollution from several sources. A comparison of pollution in one area with that of another is possible. The change in exposure from month to month at a single location can be evaluated. All of these functions were fulfilled by a survey utilizing simplified techniques which would not have been possible using dynamic samplers because of budget limitations.

Acknowledgments

This report represents a portion of the work supported in part by Research Grant S-13 from the National Institutes of Health.

Special thanks are extended to Messrs. Charles Harding, Harry Seifert, and George Rhodes, who are members of the Florida State Board of Health, for information furnished and for some of the better sketches which they contributed to this paper.

(*Continued on p 232*)

Personalia

F. Leonard Bryant was recently elected as president of the Hooker Chemical Corporation. Mr. Bryant, formerly executive vice president, succeeds Thomas E. Moffitt, president since 1957, who has been named chairman and chief executive officer. The promotion of Thomas F. Willers from vice president to executive vice president also was announced. Hooker Chemical Corporation is a sustaining member of APCA.

* * *

Edward J. Klein and **Jack Weir** have been appointed as sales engineers at the new St. Louis sales office of the Scientific and Process Instruments Division of Beckman Instruments, Inc. Mr. Klein, formerly in research with the Quaker Oats Company, will be responsible for sales of Beckman's scientific instruments. Mr. Weir will handle process instrument sales. Before joining Beckman he was with Economy Equipment Company in St. Louis.

* * *

Arthur C. Stern, Chief of the Air Pollution Laboratory of Engineering and Physical Sciences at the U. S. Public Health Service's Robert A. Taft Sanitary Engineering Center, Cincinnati, has been named to the staff of the University of Cincinnati's Department of Preventative Medicine and Industrial Health.

Mr. Stern was appointed as Assistant Clinical Professor of Industrial Health. He will serve as a consultant on advanced instruction related to air pollution. He is also a research associate in the Department of Chemical and Metallurgical Engineering in the University of Cincinnati College of Engineering.

Mr. Stern has been Chief of Air Pollution Engineering Research at the Center since 1955. He previously was associated with the Division of Industrial Hygiene, New York State Department of Labor, and the New York City Municipal Civil Service Commission. He directed an air pollution survey in New York City from 1935 through 1938.

ETHYL MAKES AGREEMENT

Ethyl Corporation announces an agreement with Catalysts and Chemicals Inc., of Louisville, Kentucky, concluded in January, to co-operate in the research, development, and testing of catalysts for use in catalytic converters for automobile exhaust gas. Ethyl Corporation has conducted extensive research in this field for several years. The co-operative program with Catalysts and Chemicals Inc., will assist in developing a commercially practical catalyst.

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Heil Lined Steel Fume Scrubber Removing Nitric-phosphoric Fumes.

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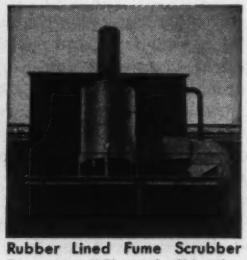

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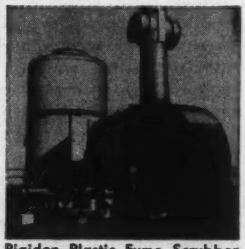

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PRESIDENTS ANNOUNCE INVESTMENT AGREEMENT

An investment agreement whereby Midwest Technical Development Corporation, Minneapolis investment firm, will provide $350,000 of new capital for expansion activities to Mast Development Company of Davenport, Iowa, was announced jointly recently by Gifford M. Mast, president of the Iowa research and development company, and by Arnold J. Ryden, president of Midwest Technical.

The investment by Midwest Technical, Mast stated, will make possible manufacture of a line of technical products to be supplied to government and industry. Several of these, including automatic recorders for two important air pollutants, ozone and olefins, are almost ready for release to the market. Balloon sondes developed by Mast Development Company for monitoring atmospheric ozone up to altitudes of 100,000 feet are now under test by the United States Army Signal Corps and Weather Bureau.

Mast Incorporated in 1945

Mast Development Company was incorporated in 1945. In addition to developing products and special equipment for many manufacturers as engineering and design consultants, the company has specialized in research, development, and design of advanced photo-optical systems, precision special purpose counters, and ultra-sensitive gas sensing and recording systems. A large part of its activity has been devoted to research and development contracts for the military services including highly specialized photographic and optical systems. In its military programs, however, it has also developed such diversified items as anti-aircraft weapons, missile handling equipment as well as a helicopter trainer.

Subcontracts Carried Out

Large subcontract programs have been performed by the company for such customers as Bendix Aviation Corporation, Remington Rand Univac, Collins Radio Company, and General Electric.

As part of the financing agreement and over-all expansion program, Midwest Technical has endorsed a plan permitting stock purchase and stock options for key technical personnel, the two presidents announced.

With the financing arrangement, John B. Hawthorne, Midwest Technical vice president, becomes a director of Mast Development. Hawthorne was formerly associated with J. M. Dain and Company, Minneapolis-headquartered investment firm, and prior to that was a senior securities analyst at Investors Diversified Services, Minneapolis.

INTERNATIONAL REPRESENTATION DUE AT APCA's FORTHCOMING CONVENTION

The 54th Annual Meeting of APCA will be held Sunday through Thursday, June 11 through 15, at the Hotel Commodore in New York City.

Leaders in the field of air pollution from the U. S. and Canada, as well as from many foreign countries, will find this an extremely profitable convention. The detailed preliminary schedule is presented in this issue of the *APCA Journal*. A new record has been set for the total number of papers to be presented. At press time, 77 papers have been accepted by George T. Minasian, Technical Program Chairman. During several days of the annual meeting concurrent sessions have been scheduled so that each registrant may devote maximum time to his area of special interest.

Ivan A. Nestingen, Under Secretary of Health, Education, and Welfare, will be the featured speaker at the President's luncheon on Tuesday. Following a pattern begun at the Los Angeles meeting, the awards of the association will again be made at the President's luncheon. This year in addition to the Frank A. Chambers Award, one Honorary Membership will be designated. Additional awards are being made to representatives of the five cities for their outstanding activities during Cleaner Air Week.

In addition to the President's luncheon, a special events schedule has also been arranged. These events include a Sunday evening "Get Together Mixer" for early arrivals, and on Wednesday evening the Annual Banquet will once again be devoted to a friendly informal affair with "Sammy's Bowery Follies" bringing the nostalgia of the Sidewalks of New York—and no speeches.

In addition to a full technical program, the plant tours and equipment displays will be of outstanding quality. Several new exhibitors have reserved space, and some of the past exhibitors have promised new and unusual equipment displays. Registrants are reminded to visit the booths since income derived from the exhibitors helps keep the registration fee at a low figure.

There is also a full schedule for registrants, wives, and families. Although Mrs. Arthur J. Benline and her committee have arranged a busy program for the ladies, there will also be free time for independent sightseeing and shopping.

Planning for the 54th Annual Meeting began a year and a half ago. Although APCA is now much more than a four-day a year organization, certainly this week in New York is the high point of the year's activities. All members are urged to attend what promises to be another memorable meeting.

Registration

Full registration information was sent to all APCA members early in April. If you did not receive your registration kit or would like additional lists sent to persons you feel would be interested in the APCA's 54th Annual Meeting, send your request to:

1961 APCA Meeting
Department of Air Pollution Control
15 Park Avenue
New York 38, New York

Registration information will be sent AIR MAIL.

SYMPOSIUM SET ON 'AIR OVER CITIES'

The agenda is being developed for a special meteorological-air pollution symposium, The Air Over Cities, to be held Monday and Tuesday, November 6 and 7, in Cincinnati. The meeting will be sponsored by the Laboratory of Engineering and Physical Sciences of the Public Health Service Division of Air Pollution.

The nucleus of the symposium will consist of a number of technical papers discussing meteorological conditions affecting air pollution concentrations over urban areas. The principal address of the meeting will be delivered by Dr. H. E. Landsberg, Director of the Office of Climatology, U. S. Weather Bureau.

Topics scheduled for discussion at the symposium are (*1*) atmospheric properties and processes which have a particular bearing or influence on air pollutant concentrations in urban areas, and (*2*) means by which quantitative knowledge of these influences can be enlarged. The symposium is planned for exchange of information between research meteorologists, operational meteorologists and air pollution control people.

Proposals for papers related to the interests of the symposium are invited. Such proposals or requests for registration information should be addressed to the chairman of the arrangements committee, R. A. McCormick, Robert Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

ENVIRONMENTAL HEALTH POSTDOCTORAL WORK GIVEN AT NYU INSTITUTE

Postdoctoral specialization in the field of environmental health is now being offered by the Institute of Industrial Medicine, New York University Medical Center, under a United States Public Health Service training grant. This program is designed to prepare persons with doctoral degrees in medicine, the medical sciences, or one of the basic sciences for research and teaching careers in this field.

The program will include specific research responsibilites; special seminars will be arranged for the trainees, and courses from the department of industrial medicine and other parts of the University will be available to supplement previous training. Fields of special interest include aerosol physics, physiology, environmental cancer, industrial toxicology, air pollution, radiological health, and radiation biology. Laboratory, epidemiological, and clinical studies will be involved. The training periods are expected to be of from one to three years' duration. Stipends are available and will vary with individual circumstances.

Application is invited from those who have recently completed their professional doctoral training, as well as those who have had some experience in the field and wish additional training.

Backgrounds particularly suitable would include physiology, pharmacology, engineering, chemistry, biochemistry, physics, statistics, epidemiology, and medicine. Inquiries should be directed to Dr. Norton Nelson, professor and chairman, Institute of Industrial Medicine, New York University Medical Center, 550 First Avenue, New York 16, New York.

RHODIA NAMES AGENTS

Jack Huppert's Conservation Products of San Antonio, Texas, and Frank W. Jarnagin, Jr., and Associates of Fort Oglethorpe, Georgia, have been appointed sales agents for Alamasks, industrial odor control chemicals, produced by Rhodia, Inc., New York. Mr. Huppert's company will supply the municipal field for the state of Texas, while Mr. Jarnagin's company will be servicing municipalities, pulp and paper industry, rubber, plastics, iron, steel and foundry, textile, rendering, and canning industries in Alabama, Western Georgia, and Tennessee.

See You at the Annual Meeting

Preliminary Program for Air Pollution Co

Monday Morning, June 12

I * Instrumentation

Chairman: ROBERT L. CHAPMAN, Beckman Instruments, Inc., Fullerton, California.

PAPER 61-39 Monitoring Atmospheric SO_2 Employing Inverse Radioactive Tracers, Richard L. Bersin, Frederick J. Brousaides, and Carlton O. Hommel, Tracerlab, Inc., Waltham, Massachusetts.
PAPER 61-40 Dynamic Calibration and Data Interpretation of a Light Scattering Instrument, Peter K. Mueller and Robert H. Givens, California State Department of Public Health, Berkeley, California.
PAPER 61-46 A Field Evaluation of the Mini-Adak II Automatic, Fluoride Air Pollutant Analyzer, Donald F. Adams and R. K. Koppe, Washington State University, Pullman, Washington.
PAPER 61-72 Development of a Condensation Nuclei Counter for Measurement of Particle Agglomeration, Robert A. Gussman, Charles E. Billings, and Leslie Silverman, Harvard School of Public Health, Boston, Massachusetts.

* Under joint sponsorship with the Instrument Society of America.

II Administrative and Legal

Chairman: BENJAMIN LINSKY, Air Pollution Control Officer, Bay Area Air Pollution Control District, San Francisco, California.

PAPER 61-18 Establishment of an Inter-Community Air Pollution Control Program, George A. Jutze and Charles W. Gruber, Bureau of Air Pollution Control and Heating Inspection, Cincinnati, Ohio.
PAPER 61-32 A Practical Air Pollution Control District Approach, John H. Fairweather, San Bernardino County, Air Pollution Control District, San Bernardino, California.
PAPER 61-67 Prosecution of Air Pollution Violations Under Common Law Nuisance, W. A. Quebedeaux, Jr., Stream and Air Pollution Control Section, Harris County Health Unit, Houston, Texas.
PAPER 61-89 Implementation of the New Chicago Air Pollution Control Ordinance.

III Health

Chairman: RICHARD A. PRINDLE, M.D., Deputy Chief, Division of Air Pollution, United States Public Health Service, Washington, D. C.

PAPER 61-26 Atmospheric Sampling for Aldehydes and Eye Irritation, Los Angeles Smog, 1960, N. A. Renzetti, Air Pollution Foundation, San Marino, California, and R. J. Bryan, Air Pollution Control District, Los Angeles County, California.
PAPER 61-76 Air Pollution and Health: New Facts from New York State, I. Jay Brightman, M.D., New York State Department of Health, Albany, New York, Alexander Rihm, Jr., and Sheldon W. Samuels, New York State Air Pollution Control Board, Albany, New York.
PAPER 61-81 Respiratory Functions and Air Pollution in Erie County, Warren Winkelstein, M.D., Department of Health, Buffalo, New York.
PAPER 61-87 The Queensboro Study on Air Pollution and Its Health Effects, M. J. Plisher, Queensboro Tuberculosis and Health Association, New York, New York.

Monday Afternoon, June 12

I * Instrumentation

Chairman: DONALD F. ADAMS, Washington State University, Division of Industrial Research, Pullman, Washington.

PAPER 61-27 Studies on the Hydrocarbon Analysis of Incinerator Effluents by Means of Flame Ionization Detector, Milton Feldstein, Bay Area Air Pollution Control District, San Francisco, California.
PAPER 61-43 Instrumentation for Olefin Analysis at Ambient Concentrations, Royal E. Rostenbach, Mast Development Company, Davenport, Iowa, and Steven W. Nicksic, California Research Corporation, Richmond, California.
PAPER 61-44 A Simple Sequential Automatic Sampler, J. Brennan Gisclard, Compact Air Samplers, Dayton, Ohio.
PAPER 61-69 Flame Ionization Hydrocarbon Analyzer, Robert L. Chapman and Robert A. Morris, Beckman Instruments, Inc., Fullerton, California.
PAPER 61-70 Analysis of Automotive Exhaust Gas, W. J. King, Dorian Swartz, and Katherine Wilson, Department of Engineering, University of California Los Angeles, Los Angeles, California.
PAPER 61-71 A New Simplified Detector for the Analysis of Organic Impurities in Atmosphere and Exhaust Gases, Edward W. Cieplinski and Leslie S. Ettre, The Perkin Elmer Corporation, Norwalk, Connecticut.

* Under joint sponsorship with the Instrument Society of America.

II Community Surveys

Chairman: WILLIAM H. MEGONN[illegible] ment of Health, Education, and Welfa[illegible]

PAPER 61-85 The Dust Count of "D[illegible] B. Jacobs, and Leonard J. Goldw[illegible] Health, New York, New York.
PAPER 61-1 Sampling Station and [illegible] veys. Part II: Suspended Particul[illegible] Stalker, R. C. Dickerson, and D. [illegible] Center, Cincinnati, Ohio.
PAPER 61-8 The Radial Distributio[illegible] tration in Nashville, Ralph I. Lar[illegible] Robert A. Taft Sanitary Engineering
PAPER 61-34 Approach to the Ch[illegible] (Benzene Soluble) in the Atmosphe[illegible] Institute of Applied Science, City U[illegible]
PAPER 61-56 The Statistical Analy[illegible] Gould, Fuel Engineering Company o[illegible]

III Incineration

Chairman: FRED R. REHM, Deput[illegible] tion, Milwaukee County, Milwaukee, W[illegible]

PAPER 61-2 Field Evaluation of C[illegible] from Municipal Incinerators, Robert [illegible] J. von Lehmden, Robert A. Taft Sa[illegible]
PAPER 61-17 Historical Review of [illegible] Office Records, John R. Sved and S[illegible] New York, New York.
PAPER 61-23 Incinerator Furnace [illegible] Harold G. Meissner, New York City [illegible] New York.
PAPER 61-36 Smokeless Burning of [illegible] Tolciss, New York University, Colle[illegible]

Tuesday [illegible]

I Instrument Developments

Chairman: HAROLD A. LEEDY, Re[illegible] search Foundation of Illinois Institute [illegible]

PAPER 61-4 Air Aloft Instrumentati[illegible] and John S. Nader, Robert A. Taft [illegible]
PAPER 61-5 Simple and Direct De[illegible] John S. Nader and William L. Coff[illegible] Cincinnati, Ohio
PAPER 61-28 A Reliable, Low-Cost [illegible] Levels, Ross V. Doughty and D. O. [illegible] Ohio.
PAPER 61-31 Experience in High Vo[illegible] Commonwealth of Pennsylvania, De[illegible]

II Control Official's Confere[illegible]

Chairman: RAYMOND SMITH, Chi[illegible] Health, Philadelphia, Pennsylvania.

PAPER 61-19 Co-operating for Clea[illegible] partment of Air Pollution Control, N[illegible]
PAPER 61-78 Administration of St[illegible] Richard E. Hatchard, Oregon Air Po[illegible]
PAPER 61-79 Administration of La[illegible] Morton Sterling, Bureau of Air Poll[illegible]
PAPER 61-82 Cultural Aspect of E[illegible] Public Health Association, New Yo[illegible]

Tuesday A[illegible]

I * Keynote Session—Ambi[illegible]

Chairman: LEONARD GREENBUR[illegible] New York, New York.

* Under joint sponsorship with Ma[illegible]

l Association's 54th Annual Meeting

PAPER 61-49 Health and Physiological Aspects, John R. Goldsmith, M.D., State of California, Department of Public Health, Berkeley, California.
PAPER 61-53 Environmental Aspects, Elmer Wheeler, Monsanto Chemical Company, Saint Louis, Missouri.
PAPER 61-54 Legal Considerations, Frank L. Seamans, Eckert, Seamans, and Cherin, Pittsburgh, Pennsylvania.
PAPER 61-55 Approaches to Air Quality Regulations, Vernon G. MacKenzie, Division of Air Pollution, United States Public Health Service, Washington, D. C.

Wednesday Morning, June 14

I Fuels

Chairman: LOUIS A. WINKELMAN, Mechanical Operating Engineer, Public Service Electric and Gas Company, Newark, New Jersey.

PAPER 61-50 Coal Combats Air Pollution, Harry C. Ballman, National Coal Association, Washington, D. C.
PAPER 61-51 Catalytic Removal of Oxides of Nitrogen from Automobile Exhausts, William E. Scott, Scott Research Laboratories, Perkasie, Pennsylvania.
PAPER 61-52 The Gas Industry and Its Contribution to Air Pollution Control, C. George Segeler, American Gas Association, New York, New York.

II Control Equipment

Chairman: CHARLES S. MANERI, Chief, Air Pollution Control Section, New York State Department of Health, Albany, New York.

PAPER 61-9 An Analysis of Mechanical Shaking in Air Filtration, George William Walsh, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
PAPER 61-15 Performance Test Technique for Ejector Venturi Scrubber, L. S. Harris, R. Hartenbaum, Schutte and Koerting Company, Cornwells Heights, Pennsylvania.
PAPER 61-16 New Baghouse Installation for Clearing Smelter Gases, David L. Watts and James F. Higgins, Phelps Dodge Refining Corporation, New York, New York.
PAPER 61-58 Glass Fibers and Their Use as Filter Media, William H. Willis, Jr., Alfred Marzocchi, and Frank J. Lachut, Owens-Corning Fiberglass Corporation, New York, New York.
PAPER 61-66 Evaluation of Air Cleaners for Occupied Spaces, D. A. Lundgren, Kenneth T. Whitby, Andrew R. McFarland, Arthur R. Kydd, and Richard C. Jordan, University of Minnesota, Institute of Technology, Minneapolis, Minnesota.

III Meteorology

Chairman: IRVING A. SINGER, Meteorologist, Brookhaven National Laboratories, Upton, Long Island, New York.

PAPER 61-3 Analysis of Seasonal Variations in Air Pollution Levels, Elbert C. Tabor and Donald H. Fair, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
PAPER 61-6 Relationships Between 24-Hour Mean Air Quality Measurements and Meteorological Factors in Nashville, Tennessee, Donald B. Turner, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
PAPER 61-13 Composition of Natural Fresh Air, Claude J. D'Angio, Airkem, Inc., New York, New York, and Amos Turk, City College of New York, New York, New York.
PAPER 61-14 The Behavior of Dense Stack Gases, Frank T. Bodurtha, Jr., E. I. du Pont de Nemours and Company, Wilmington, Delaware.
PAPER 61-62 Analysis of Smoke Observations at Ottawa, Canada, R. E. Munn, Canada Department of Transport, Toronto, Canada, and C. R. Ross, Department of National Health and Welfare, Ottawa, Canada.

Thursday Morning, June 15

I Developments

Chairman: HERBERT J DUNSMORE, Chief, Bureau of Air Pollution Control, Department of Health, Pittsburgh, Pennsylvania.

PAPER 61-12 Air Sanitation Developments, Lauren B. Hitchcock. Lauren B. Hitchcock Associates, New York, New York.
PAPER 61-65 Flue Gas Cleaning Efficiency Required to Minimize Air Pollution Effects, Wesley C. L. Hemeon, Hemeon Associates Pittsburgh, Pennsylvania.
PAPER 61-83 Solving a Valley Air Pollution Problem, The Seward Generating Station of the Pennsylvania Electric Company.
Public Relations, Ralph F. Bovier, Pennsylvania Electric Company, Johnstown, Pennsylvania.

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(*continued from p 229*)

Research and Development, Alexander J. Tigges, Jackson and Moreland, Inc., Boston, Massachusetts.
Air Sampling Survey, William A. Verrochi, Jackson and Moreland, Inc., Boston, Massachusetts.
And Additions, W. H. Lambert, Pennsylvania Electric Company, Johnstown, Pennsylvania.

PAPER 61-80 The Effect of Temperature on Photo Chemical Oxidant Production in a Bench Scale Reaction System, F. C. Alley, Department of Sanitary Engineering, University of North Carolina, Chapel Hill, North Carolina.

II Meteorology

Chairman: A. VAUGHN HAVENS, Professor, Department of Meteorology, Rutgers, The State University, New Brunswick, New Jersey.

PAPER 61-29 A Study of Ozone Occurrence in Northern Greenland, Herbert C. McKee, Southwest Research Institute, San Antonio, Texas.
PAPER 61-35 Diffusion of Vented Gases Around Buildings, James Halitsky, Daniel Marchi, Jack Golden, New York University, College of Engineering, New York, New York.
PAPER 61-63 Pollen Sampling and Dispersion Studies at Brookhaven National Laboratory, Gilbert S. Raynor, Maynard E. Smith, Irving A. Singer, Brookhaven National Laboratory, Upton, New York.
PAPER 61-74 A Comparison of Observed Plume Rises with Values Obtained from Well-Known Formulas, Harry Moses, Argonne National Laboratories, Argonne, Illinois, and Gordon H. Strom, New York University, New York, New York.

III Research

Chairman: RAYMOND M. MANGANELLI, Professor, Department of Sanitation, Rutgers, The State University, New Brunswick, New Jersey.

PAPER 61-10 The Microscopic Identification of Particular Dusts, Marvin A. Salzenstein and Walter C. McCrone, Walter C. McCrone Associates, Chicago, Illinois.
PAPER 61-11 The Adhesion of Solid Particles to Solid Surfaces, Morton Corn, School of Public Health, Harvard University, Boston, Massachusetts.
PAPER 61-37 Aerosol Sampling for Electron Microscopy, Charles E. Billings and Leslie Silverman, School of Public Health, Harvard University, Boston, Massachusetts.
PAPER 61-38 Light and Dark Phase Oxidant Production in a Non-Urban Atmosphere, Lyman A. Ripperton, School of Public Health, University of North Carolina, Chapel Hill, North Carolina.

Thursday Afternoon, June 15

I Automotive

Chairman: A. LANDON BAKER, JR., Associate Chemical Engineer, Sun Oil Company, Marcus Hook, Pennsylvania.

PAPER 61-7 Chemical Methodology in Auto Exhaust Studies, John E. Sigsby, Jr., Lois J. Lage, Thomas Bellar, and Mary L. Eisele, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
PAPER 61-30 A Comparison of Various Sources of Automotive Emissions, Herbert C. McKee and Kenneth D. Mills, Southwest Research Institute, San Antonio, Texas.
PAPER 61-48 An Air Pollution Phytotron—A Controller Environment Facility for Studies into the Effects of Air Pollutants on Vegetation, Donald F. Adams, Washington State University, Pullman, Washington.
PAPER 61-86 The California Control Program for Motor-Vehicle-Created Air Pollution, John T. Middleton and Diana Clarkson, Motor Vehicle Pollution Control Board, University of California, Agricultural Experiment Station, Riverside, California.

II Planning and Administration

Chairman: ARTHUR C. STERN, Chief, Laboratory of Engineering and Physical Science, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

PAPER 61-20 Public Relations for the Control Agency: A Practical Approach, Kenneth Kowald, New York City Department of Air Pollution Control, New York, New York.
PAPER 61-59 Environmental Performance Standards: Their Place in Planning and Zoning Regulations, William T. Ingram, Consulting Engineer, New York, New York.
PAPER 61-60 An Air Pollution Rating Index System, Seymour Calvert, Case Institute of Technology, Cleveland, Ohio.
PAPER 61-88 An International Jet Pilot Looks at Air Pollution, Captain Robert N. Buck, Trans World Airlines, Westfield, New Jersey.

III Processing

Chairman: LOUIS C. McCABE, President, Resources Research, Incorporated, Washington, D. C.

PAPER 61-25 Spectrographic Trace Analysis of Air-Borne Particulates, M. M. Braverman, Frederick A. Masciello, and Vera Marsh, New York City Department of Air Pollution Control, New York, New York.
PAPER 61-61 Air Pollution Control for the Fish Dehydration Industry, Leonard C. Mandell, Consulting Research Engineer, Providence, Rhode Island.

(*Continued on p 231*)

Tours Highlight Annual Meeting

Tour I

CONSOLIDATED EDISON COMPANY—Astoria, Long Island Plant. An unusual power plant which uses coal, oil, and gas as fuels.

Tour II

CONSOLIDATED EDISON COMPANY—Indian Point, New York. New atomic energy power plant.

Tour III

BOAT TRIP around Manhattan Island with emphasis on items of interest to APCA's members. This trip will be in conjunction with ladies' trip.

MILLION DOLLAR CONTRACT AWARDED RESEARCH-COTTRELL

A U. S. Navy contract for more than one million dollars has been awarded to Research-Cottrell, Inc., for close to 300 air-cleaning precipitators to be used in nuclear submarines, it was announced by James P. Kneubuhl, president of the Company.

The precipitators are capable of cleaning nearly one million cubic feet of air per minute. Individual units aboard the Navy's new nuclear submarines will provide clean air for personnel to breathe during the extended periods the subs are under water.

Delivery of the units extend from 1961 to July 1962. Each cleaner will have its own electrical power supply. Most of the new precipitators will have guaranteed efficiencies of 95% in removing dust, cigaret smoke, engine oil mist, cooking odors, lint, and other particles from the air.

(*Continued on p 232*)

LADIES' PROGRAM

Coffee hour at the hotel each morning.

1 Fiberglass Fabrics tour.
2 Matinee at the famous Radio City Music Hall.
3 Visit of Steuben Glass display.
4 Boat trip around Manhattan Island.

Children are welcome at both the hotel and on the tours. Competent baby-sitters available through the Housekeeping Department at the Hotel Commodore.

VISIT THE 1961 APCA EXPOSITION

At press-time, the following booth spaces for exhibiting companies at the 1961 APCA Exposition, which will be held at the Annual Meeting, were designated.

Extra features of the Exposition will include a complimentary refreshment booth within the exhibit hall for the benefit of visitors and representatives, as well as expensive electric appliance attendance prizes for which visitors may register at each booth.

Exhibitors and their booth numbers are listed below.

1—Research Appliance Company, Allison Park, Pa.—automatic air sampling equipment.

3—The Chemical Construction Corporation, New York, N. Y.—scrubbing equipment.

27—Gelman Instrument Company, Chelsea, Mich.—various test instruments for air pollution control work.

5—The Ducon Company, Mineola, L. I., N. Y.—dust collecting equipment.

7—Dustex Corporation, Buffalo, N. Y.—dust collecting equipment.

14—Joseph Goder Incinerators, Chicago, Ill.—latest model incineration equipment.

22—Mikro-Products, Pulverizing Machinery, Division of Metals Disintegrating Company, Inc., Summit, N. J.—jet action Mikro-Pulsaire collector designed for maximum recovery of nuisance, noxious, and high value dust.

15—Barneby-Cheney Company, Columbus, Ohio—activated charcoal equipment for odor control.

11—Peabody Engineering Corporation, New York, N. Y.—scrubbing equipment.

16—Wheelabrator Corporation, Mishawaka, Ind.—mechanical dust collection devices.

17—Morse Boulger, Inc., New York, N. Y.—latest model incinerators.

18—Scientific and Process Instruments, Div. of Beckman Instruments, Inc., Fullerton, Calif.—lab and process gas analyzers.

19—Catalytic Combustion Corporation, Detroit, Mich.—catalysts and fume combustion systems for air pollution control and heat recovery.

21—Airkem, Inc., New York, N. Y.—industrial odor counteractants for atmospheric odor control and for the neutralization of effluents from manufacturing processes.

24—Oxy-catalyst, Inc., Wayne, Pa.—catalytic fume elimination devices and systems for industry, automobiles, buses, and trucks.

28-29—The John Wood Company, Bernardsville, N. J.—the new concept in gas scrubbers.

13—Rhodia, Inc., New York, N. Y.—chemical odor control products.

20—Heat Timer Corporation, New York, N. Y.—instruments.

6—Royco Instruments, Inc., Palo Alto, Calif.—instruments.

4—Pantex Manufacturing Company, Pawtucket, R. I.—automotive exhaust devices.

2—The Gulick Henderson Laboratories, New York, N. Y.

25—R. G. White Manufacturing Company, New York, N. Y.

Booth not assigned—American Sterilizer Company, New York, N. Y.

PRELIMINARY PROGRAM

(*Continued from p. 230*)

PAPER 61-64 Some Data and Observations on Combustion of Gaseous Effluents from Baked Lithograph Coatings, Abraham Wallach, Industrial Hygiene Services, Newark, New Jersey.

PAPER 61-75 Odor Control in the Food Processing Industry, Alfred R. Miller, General Foods Corporation, White Plains, New York.

PAPER 61-84 Oxidation of Black Liquor by Air Under Pressure, Adelberto A. Tirdao and Mario V. Guevara, Fabricas De Papel, Loreto y Pena Pobre, South America, Villa Obregon, D. F., Mexico.

PAPER 61-33 Effects of Ethylene on Cotton and Cowpea, Walter W. Heck, The Agricultural and Mechanical College of Texas, College Station, Texas.

Next Issue

Highlights from the Annual Meeting Will Be Featured in June

PROCEEDINGS of 1960 ANNUAL MEETING AVAILABLE Through HEADQUARTERS

Committee Meetings Scheduled for Annual Meeting

	SUNDAY—June 11, 1961	
	Board of Directors	2:00 p.m.
A-5.3	Exhibits	6:00 p.m.
TA-7	Odor & Gas Treatment	2:00 p.m.
	MONDAY—June 12, 1961	
A-3	By-Laws	9:00 a.m.
S-1	Publications	
S-1.1	Editorial Review	9:00 a.m. (combined meeting)
S-4	Legal	10:00 a.m.
	Board of Directors	2:00 p.m.
S-9	Consultants	2:00 p.m.
TI-1	Marine	2:00 p.m.
	TUESDAY—June 13, 1961	
S-8	Planning & Zoning	9:00 a.m.
TA-5	Dust, Fumes, Mists & Fog Collectors Committee	9:00 a.m (all day meeting)
TI-2	Chemical	9:00 a.m.
TI-3	Petroleum	9:00 a.m.
TI-4	Coal	9:00 a.m.
TI-5	Public Utilities	9:30 a.m.
TI-6	Steel	9:30 a.m.
TA-9	Power Boiler Equipment Information	9:00 a.m.
	Business Meeting	4:00 p.m.
	Local & State Control Officials Forum	8:00 p.m.
	WEDNESDAY—June 14, 1961	
	Technical Council	9:00 a.m.
	Sectional Meetings (Mid-Atlantic Section)	9:00 a.m.
	THURSDAY—June 15, 1961	
A-1	Membership	9:00 a.m.

WILLIAM T. INGRAM

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REPRINTS
of
Journal Articles
and
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Available through APCA HEADQUARTERS

Help Boost APCA Membership

CONTRACT AWARDED

(*Continued from p 230*)

Custom-designed to fit tight sub quarters, the precipitators will have over a dozen different configurations. All are of the two-stage type having a charging section of 17 kv, and a collecting section of 7 to 17 kv. To meet minimum clearing requirements and for performance reliability, the compact precipitators will be negatively polarized, unlike positively charged commercial air cleaners of conventional design. Several of the new units will be high-velocity, high-efficiency precipitators of a type recently developed.

MANUFACTURERS HEAR API PROGRESS REPORT

Leading oil-heat equipment manufacturers and other persons pursuing research or development in the field of distillate fuel combustion met here March 14 and 15 to participate in the first progress report and forum of a new research program sponsored by the Marketing Division of the American Petroleum Institute.

"Our broad objective," said V. A. Bellman, API vice president for Marketing, "is to develop new principles and technology, and to pass the information on to equipment manufacturers as a valuable aid in producing less expensive, more efficient and service-free oil-burning equipment."

He noted that the oil industry program, valued at about $1,000,000 for this first year, is aimed at supplementing, not duplicating, present research efforts by the equipment manufacturers themselves.

J. L. Minner, chairman of the research subcommittee, stressed that "activities will be carried to the point of demonstrating principles, but not to the point of providing final equipment design. The research will not come up with a burner to end all burners, or a burner designed, standardized and promoted by API."

Operations of API, its Marketing Division, and especially the Fuel Oil Committee, were explained by A. J. Becker, the committee chairman.

Air-Borne Fluorides

(*Continued from p 225*)

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Operating PROCEDURES *Which Help* REDUCE *Air* POLLUTION

Informative Report No. 5

COMMITTEE TI-7

The purpose of this report is to point out recommended practices and operations intended to reduce air pollution.

The practices that are recommended will do a couple of things. First, there should be a reduction in emission and localized fall-out of larger particles. This will also reduce the in-plant and roof-top clean up time. Secondly, small particles will be released at maximum plant elevations which is usually better than low level release. The recommended practices, if adhered to, can bring about a decrease in over-all emissions. Of course it is recognized that in some geographical areas, and in some neighborhood situations, even these best practices will not go far enough to meet the problem without the installation of collectors.

In other cases, depending on local conditions, the adoption of these recommended practices may be sufficient to control emissions to an acceptable degree.

These procedures, listed below, will undoubtedly suggest others to alert foundrymen:

1 Maintain control over melting rates in order to obtain as near as possible a uniform rate of melting. This can be done by:
   a The installation of a holding ladle; or, if a holding ladle is already in use, by increasing its size. The steady melting rate thus made possible reduces emission peaks.
   The installation of an air-rate controller in order to maintain a uniform flow of combustion air through the cupola tuyeres. This eliminates pressure puffs which tend to increase the amount of emissions.
   c Uniform charging of the cupola, both in terms of accurate weight of charge components and in terms of uniform distribution of scrap in the charge. Other qualities of the scrap being equal, it is preferable to mix dirty scrap with clean scrap rather than to charge all dirty scrap on one day and all clean scrap on another.
2 Avoid rough handling of the cupola coke in order to reduce the amount of fines carried out of the stack. This may require:
   a Changing the method of adding coke to the charging bucket in order to reduce the distance the coke falls and to eliminate coke breakage. Where coke and metal are placed in the same bucket, the coke should be added last.
   b Screening or forking the coke or drilling holes in the chute bottom plates to drop out fines.
   c Keeping the cupola stock height as high as possible in order to keep the charges from breaking the coke. This also has the effect of preventing escape of combustible fines before they are consumed, since a deep bed will serve as a sort of primary collector.
3 Use clean, well screened, unweathered limestone to minimize the amount of limestone dust discharged to atmosphere.
4 Briquette or inject all metal turnings and chips before charging. The injector is a device which injects chips or turnings into the combustion zone of the cupola just above the tuyeres. Injection is accomplished by means of air pressure. This device prevents loss of fine chips through the stack and reduces the emission of metallic fines which are sometimes a neighborhood nuisance and which may cause damage to the finish of automobiles parked nearby.
5 Clean greasy scrap before charging. This may require the installation of degreasing equipment or smokeless burn-off equipment. If economically practical, do not buy greasy scrap. In addition to grease other nonmetallic materials are sometimes present which can be handled by smokeless burn-off rather than by degreasing.
6 Use gas torches, oil burners, or electric igniters rather than wood when lighting the cupola bed. With this equipment the cupola bottom can be heated to much nearer the desired molten iron temperature before melting starts; there will be less arching of the coke bed than would be the case if wood were used as the means of ignition; and the first metal tapped is hotter.
7 Install cupola stack-gas igniters at the charging-door level. These will consume unburnt gases and combustible particles when sufficient secondary air is available. Igniters, however, will have no effect on metal oxides or fly ash.
8 When charging openings are too large, the effective draft of the cupola stack is reduced. This sometimes causes emissions to be discharged from the charging opening rather than from the top of the stack. This has the effect of:
   a Reducing stack-gas combustion time.
   b Emitting pollutants at a lower elevation thus losing any advantage of stack height.

Where mechanical charging equipment is used, the charging opening must be large enough to admit the charge buckets. If the size of such opening results in the conditions noted under item 8, then a sliding door—either the horizontal or vertical-movement type—may be installed.

The door's movement may be timed with the charge bucket's movement by electrical or mechanical means. When

not charging, sufficient opening should be provided so that the in-draft of air will prevent escape of emissions through the opening.

9 Where it is compatible with a particular metallurgical nonferrous practice, lead and zinc fume can be held to a minimum by adding lead and zinc pig to the molten copper-base melt just prior to pouring rather than melting the pig in the cupola or furnace with the copper scrap. This also reduces melting losses.

Lead and zinc have higher vapor pressures than copper and hence will constitute the principal pollutants when brass or bronze is melted.

In practice, the copper-base scrap is melted and heated to a temperature so much higher than the pouring temperature that after the pig is added to the tapped-out melt, the temperature is reduced to the correct degree.

10 Where the practice permits, gates, runners, and risers should be cleaned with the casting. When these returns are then remelted, there will be a reduction in the silica fraction of the emissions.

11 In the manufacture of ductile iron, the emissions from the magnesium inoculation can be reduced by using the plunging technique.

12 Where powdered coal is used as the fuel in core ovens, annealing, heat treating or melting, use of available coals with the lowest ash content and maintaining proper air-fuel ratio with good mixing at the burner will yield a relatively clear stack plume.

13 Where nuisance dusts are escaping from collectors serving such operations as casting cleaning and shakeout, maintenance of the dust separating system to maintain original equipment design operating specifications can often reduce emissions.

Informative Report No. 6

Legal Limitations on Emissions from Foundry Operations

Air Pollution Control Is a Local Problem

A single set of limitations on industrial atmospheric emissions applied on a nation-wide basis is not practical because of local differences in meteorology, topography, population, etc., and in the type of pollution problem existing. For example, in the Portland-Seattle area, a significant pollution problem arises from sawdust burning, in Pittsburgh the prime offender has been smoke from soft coal used as a fuel: while in southern California, organic vapors and oxides of nitrogen are thought to be of major significance. Just as the pollution type varies from place to place, so the contribution of foundry operations also varies as does the degree to which these emissions should be controlled. For example, an air pollution ordinance relating to foundries which would be adequate for Los Angeles would work an unnecessary hardship in Sioux City, Iowa, and one satisfactory for Sioux City would be inacceptable in Los Angeles. In short, air pollution control, where required, should be dealt with as a local, not as a national, problem.

While it is impossible, therefore, to establish universally applicable limits for emissions from the various foundry operations, it is, nevertheless, reasonable and, in fact, desirable to outline certain ordinance provisions which are compatible with foundry operations as well as some which are not properly applicable.

Recommended Ordinance Provisions Relating to Foundry Air Pollution Emissions

Two basic types of operations are performed in a foundry. These are (*1*) the high-temperature operations of metal melting and (*2*) the low-temperature operations such as:

- *a* Sand handling in the production of cores and molds.
- *b* Shakeout of molds and castings.
- *c* Core knockout of cold castings.
- *d* Casting cleaning including tumbling, shot or sand blasting, chipping, grinding, burning off of sprues, and flame washing.

For these operations it is recommended that air pollution ordinances for controlling emissions should include two types of limitations. One type should be stated in terms of pounds of emission per 1000 lb of process weight per hr.* This type of limitation may reasonably be applied to metal melting and pouring operations. Ideally, allowable emissions should be specified individually for each type of industrial process, but since this is generally not feasible at our present stage of development, an across-the-board limit, at least, does not favor one type of process over another. Codes of this type have been criticized in the past as being too strict; it seems, however, that the critics confuse the philosophy with the severity. Actually, this method of fixing emission limits can be severe, moderate, or lenient, depending entirely upon the needs of the local community.

The second type of limitation should be expressed as allowable outlet concentrations in terms of grains of particulate matter per standard cubic foot of air. This type is recommended for application to sand handling and casting cleaning operations. The former type of limitation is not satisfactory here because the term, "process weight per hour," is difficult to define in these cases. It may be argued that deliberate dilution of exhaust streams is possible to avoid violations, but such practices can be easily dealt with by a control officer having a knowledge of ventilation volumes† required for such operations.

Basis for Determining Allowable Limits of Emissions

To those charged with the responsibility of enacting an air pollution ordinance for a specific locality, it may be helpful to suggest a basis for determining the allowable limits of emissions.

It is known that equipment is available for collecting 99+% of the emissions from metal melting operations. Admittedly it is the most expensive type. However, local conditions may be such that collection of emissions to a degree of no visible discharge is unnecessary and unduly onerous.

The following information may be helpful in determining a permissible limit of emissions.

For High-Temperature Operations

The emissions from a cupola in normal operation will range from three to 15 lb per 1000 lb process weight per hr. A fair average is eight lb per 1000 lb.

It is estimated that the average cupola in the United States melts in the range of one half to 30 tons per hr, with an average rate of five tons per hr.

These values yield an average emission rate of 80 lb per hr and a range of $1^1/_2$ to 900 lb per hr.

Emissions from electric furnaces range from two to four lb per 1000 lb process weight per hr and average three lb per 1000 lb. The most common melting

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* Process weight in this report means "The total weight of all materials (except air) introduced into any specific process which process may cause any discharge into the atmosphere."

† Satisfactory exhaust air volumes have been published in *Engineering Manual for Control of In-Plant Environment in Foundries*, American Foundrymen's Society, Des Plaines, Illinois, 1956.

rate averages two tons per hr. These values yield an average emission rate of 12 lb per hr and a range of eight to 16 lb per hr.

For Low-Temperature Operations

Low-temperature operations, when exhausted to atmosphere using the standard AFS air volumes, rarely produce a dust loading in excess of 1.0 grain per cubic foot of air.

The difficulty of cleaning emissions from those operations is not nearly so great as for those from metal-melting operations. In fact, most foundries already use dust arresters for low-temperature emissions exhausted to atmosphere if only to avoid the plant nuisance and expensive property maintenance otherwise involved.

Even the medium-efficiency dust arresters can clean such emissions to a degree where nuisance complaints are eliminated.

In foundries, where air contaminants from low-temperature operations are not exhausted to atmosphere, they constitute an in-plant problem rather than an external air-pollution problem.

With these facts in mind, it should be easier to fix a reasonable limit of emissions according to the exigencies of a particular locality. For example, in the case of metal-melting operations, an emissions-limit curve based on process weight per hr can be fixed to suit local needs.

Ordinance Provisions Not Applicable to Foundry Melting Operations

Certain ordinances which have been enacted by various legislative bodies throughout the country have not recognized the differences between foundry metal melting processes and combustion processes. Consequently, a number of ordinance provisions have been enacted, and are being enforced, which were designed specifically for application to combustion effluents and which cannot logically be applied to metal melting operations. Among these are:

Ordinances Which Restrict Stack Discharges by Comparing Their Opacity with the Ringelmann Chart or Other Visual Smoke Inspection Guides. The Ringelmann Chart* was originally designed to measure only black smoke emissions from coal-burning equipment. Such guides can have a definite utility for this purpose since the opacity of a plume from a carbonaceous fuel burning operation is related to the degree of combustion of the fuel. Their use to measure nonblack emissions such as iron oxide or zinc oxide fumes from metal melting operations was never intended nor foreseen. Their use may be proper for the evaluation of emissions from fuel-burning equipment since adjustments in firing practice to achieve proper combustion will bring about concurrent reductions in plume opacity. Stack emissions from foundry melting operations, however, are normally not black, basically are not smoke, and cannot usually be reduced in opacity by process adjustment.

Metal melting operations generate quantities of fumes of metallic oxides which have high light scattering power because of the extremely fine size of the particulate matter emitted. These metal oxide fumes vary from white to dark brown in color, depending upon the metal being melted, and their average particle size is on the order of 0.5 micron. A Ringelmann number, however, when applied to these emissions is meaningless from a technical standpoint.

Ordinances Which Call for Adjustment of Volumetric Discharge Rate to That Having a Specified Percentage of Carbon Dioxide. Ordinances containing provisions for adjustment of emission rates to 12% CO_2 (such as the American Society of Mechanical Engineers Sample Sections for a Smoke Regulation Ordinance) are not properly applicable to foundry metal melting operations because the percentage of carbon dioxide in metallurgical stack gases has no relationship whatsoever to the efficient operation of these processes. The percentage of CO_2 in foundry stack gases may very properly range from zero upwards depending upon the metallurgical process used. For example, no combustible fuel at all is used in the electric-arc furnace so an adjustment to 12% CO_2 in this case would yield the obviously ridiculous answer of an infinite volumetric discharge rate. As further evidence of the inapplicability of such an adjustment to cupola-stack gases, it may be pointed out that limestone ($CaCO_3$) normally charged into a cupola, decomposes on calcining to lime (CaO) and carbon dioxide (CO_2). One mole of limestone will yield one mole of lime and one mole of carbon dioxide. Thus by charging far more limestone than is necessary, the CO_2 content of the stack gas could be increased without in any way lowering the amount of particulate emission. The 12% CO_2 requirement is undoubtedly quite applicable to boiler installations. The title "ASME Sample Sections for a Smoke Regulation Ordinance" clearly indicates that the extension of this ordinance to metal melting operations was never visualized or intended by the ASME.

To illustrate the effect of such corrections on cupola emissions consider the following: a boiler stack and a foundry cupola stack discharge 0.60 lb of particulate matter per 1000 lb of stack gases, and each discharges the same weight of stack gas per hour. The weight rate of emissions is then clearly equivalent. If the CO_2 content of the boiler emission is 10%, the adjusted rate for control purposes would be $(12 \times 0.60/10) = 0.72$ lb of particulate per 1000 lb of stack gas. On the other hand, in a cupola melting operation, combustible fuel is a small fraction of the charge (iron to coke ratios are as high as 11:1), and the CO_2 content of the off-gases may be, and often is, on the order of five percent even with complete combustion of the coke. Hence at five percent CO_2 content, the adjusted rate for the cupola stack would be $(12 \times 0.60/5) = 1.44$ lb/1000 lb of stack gas. Such a regulation appears, therefore to burden metal melting operations with much more stringent control requirements than fuel-burning operations, even though the foundry stack may contribute no more and perhaps much less to air pollution on an absolute basis.

Ordinances Which Call for Adjustment of Volumetric Discharge Rate to That at a Specified Temperature. As in the case of corrections for CO_2 content, volume corrections to a given temperature (usually 500°F) were originally proposed for application to boiler equipment. For this purpose, such an adjustment has merit since a stack temperature in excess of 500°F normally indicates an incorrectly operated and inefficient boiler. In contrast to a boiler stack, however, a foundry iron-melting - cupola - stack - gas temperature may reach 1700°F or higher under efficient operating conditions. An ordinance of this type, therefore, also imposes more strict control requirements on foundry metal melting operations. For example, as in the preceding section, consider both a cupola stack and a boiler stack which are discharging the same weight of gas per hour. Each contains 0.60 lb per 1000 lb of stack gas. If the boiler emission is at 600°F, and the local ordinance requires correction to 500°F, the adjusted stack loading would be $(460 + 600)/(460 + 500) \times 0.60 = 0.66$ lb/1000 lb of gas. A cupola stack, discharging at 1500°F, on the other hand, would have an adjusted loading for control purposes of $(460 + 1500)/(460 + 500) \times 0.60 = 1.25$ lb/1000 lb stack gas. Once again a foundry operator is severely handicapped by an ordinance provision never intended for application to his emissions.

Types of Ordinances Not Recommended for General Application

Ordinances Which Call for Source Control on the Basis of Ground Level Concentrations of Pollutants. Some areas have enacted air pollution codes which have as their criterion for con-

* ASTM Definition: "*Ringlemann Chart*—A chart used in air pollution evaluation for assigning an arbitrary number, referred to as smoke density, to smoke emanating from any source."

trol the measurements of pollutant concentrations at ground level in the field, rather than at the source. The concept is sound because there is no need to limit stack emissions if atmospheric dispersion is good and no nuisance or damage is occurring. In one such code,* control is required only when dust-fall rate exceeds 45 tons per square mile per month above the normal background, or when suspended particulate concentration exceeds 250 micrograms per cubic meter above normal background. It would be desirable if this type of ordinance could be applied and enforced since it automatically adjusts control requirements for the differences in meteorology and topography from place to place.

However, it is not felt that such an ordinance can be practically applied in industrial areas because: (1) no feasible method is available for determining "normal background" values for a given area, (2) no correlation exists between dust-fall rates and emissions from specific stacks (in other words, it is impossible to determine which sources should be controlled and how efficient controls should be on any given source), and (3) control equipment suppliers cannot give guarantees of ordinance compliance since efficient control of any one source would not decrease the area dust-fall rate by any easily predictable amount.

Ordinances Which Have Emission Limitations Based upon Plant Property Area. Codes of this type relate allowable source concentrations to the area of the property upon which the source is located, the theory being that the larger the property area the less contamination that will be transported onto adjacent land. It is felt that such an ordinance is unrealistic in the vast majority of cases since the theory upon which it is based holds only if the source is near the geometric center of the plant property, only if all discharges are emitted at the same elevation, only if all the contaminant are particulates large enough to settle out, etc., and since the contribution to pollution by any source is determined by both the *quantity* of contamination and the *type* of contaminant involved. There is no consistent relationship between plant area and the pollution contributions of plants and different processes.

Informative Report No. 7

Available Control Equipment

A knowledge of equipment available and its proper application to the various foundry operations is essential for efficient control of emissions from exhaust system discharge.

The range of problems pertinent to the selection of control equipment is very broad and in order to achieve a good selection, an understanding of them must be developed. One should take advantage of the manufacturer's know-how before proceeding with procurement.

Control Equipment Available

For the purposes of discussion, we have grouped control equipment by type in addition to limiting coverage to those usually found in the foundry industry.

Miscellaneous Characteristics of Control Equipment Are Detailed as per Figure 1.

Dust Collection Equipment Cost

The equipment cost, especially on an installed basis, is difficult to estimate. A thorough knowledge of the factors included or the items not included is necessary. Factors which make useful cost estimates difficult to furnish include:

Price Versus Capacity. All dust collector prices per cfm of gas handled will vary with the volume involved. The smaller the volume, the higher the cost per cfm. The break point, where the price per cfm cleaned tends to level off, will vary with design but seems to be between 10 and 20,000 cfm except for electrical precipitators which don't level off until between 200 and 300,000 cfm.

Accessories Included. Careful analysis of components of equipment included is very important. Some collector designs include exhaust fan, motor, drive, and starter. In other designs, these items and their superstructure must be secured from other sources by the purchaser. Likewise, while dust storage hoppers are integral parts of some collector designs, they are not provided in other types. Duct connections between elements may be included or omitted. Recirculating water pumps and/or settling tanks may be required and may not be included in the equipment price.

Installation Cost. Installation cost can equal or exceed the cost of the collector, depending on method of shipment (completely assembled, subassemblies, or completely knocked down) on location which may require expensive rigging to put in place and on expensive supporting steel and access platforms. The cost picture can be measurably influenced by the need for water and drain supply, special or extensive electrical work, and expensive material handling equipment for collected material disposal.

Special Construction. Prices shown necessarily assume standard or basic construction. Increase in cost for corrosion resisting materials, special high temperature fabrics, insulation and/or weather protection for outdoor installations, can introduce a multiplier of one to four times standard construction cost.

Collection Range as to Particle Size

Dust in exhaust systems covers a wide range in loadings and particle sizes. Concentrations can range from 0.1 to 20.0 or more grains of dust per cubic foot of air. Usual dusts range from 0.5 to 100 or more microns ($^1/_{25,000}$ in.) in size. Deviation from mean (the range of over and under the mean) will also vary with the material. Some indication of the mean particle size and deviation of typical contaminants has been included in the composite chart, Fig. 2.

If the particles are coarse and the range of sizes limited, it is easy to remove these particles and with less expensive equipment. The heavier the dust loadings, the higher the collector efficiency required to obtain the same degree of air cleaning. For a given exhaust volume and particle size, a collector with 50% collection efficiency and a loading of one grain per cubic foot will discharge with the cleaned air the same number of pounds as a device with a loading of five grains and 90% efficiency. Such illustrations do not give a complete picture because of particle size importance and the tendency for large particles to settle quickly.

Total Power Used

Many writers on this subject have given the pressure drop through the collector as a means of evaluating the power required. However, some collectors furnish their own suction, and pressure drop is only a function of fan efficiency. Total power required is to include that required for water circulation, bag rapping mechanisms, net pressure drop through the collector (if any), slurry pumping, and sludge disposal. In order to give a uniform reference, we have assumed a hypothetical system pressure loss outside the collector of four-inch W.G.

Space Requirements

This factor is somewhat self-explanatory, but it can be very important in collector selection. However, cost can be inversely proportional to size. If pressure drop through the collector

* State of Oregon.

Type	Description	General Application
Louvre Type	Gas strikes closely spaced louvres at an angle, rebounds, and travels toward outlet where secondary air circuit takes it to separate collector.	Used in power plants for fly ash removal.
Gas Reversal	Gas stream changes direction abruptly projecting dust into dead air space in which gravity settling takes place.	Used as a precleaner only.
Low Pressure Drop Cyclone	Centrifugal forces spin heavier dust particles against conical section and gravity takes dust to bottom discharge; the cleaned air escaping at the top.	For removing coarse dust in light loads such as wood working, grain flour and feed mills.
High Pressure Drop Cyclone	Increased centrifugal forces obtained by using a number of small diameter tubes in parallel.	Used primarily for boiler fly ash and frequently as primary collector on kilns, dryers, and coolers.
Mechanical Cyclone	Dust precipitated by centrifugal forces created by numerous specially shaped fan blades.	Same as H.P. Drop or multiple but used where space requirements are smaller.
Conventional Fabric	Dust filtered or strained by screens, bags, or tubes. Shaking, rapping, or vibrating devices recondition filter media.	Extremely high efficiencies on applications where dry reclamation of dust is desired or dry disposal will not be a problem.
Reverse Jet Fabric	Same as conventional. Use of reverse jet of air for reconditioning permits higher air to cloth ratios because of constant cleaning.	Same as conventional.
Electrostatic Precipitators	Air passes through high potential electric or ionizing field where charged particles precipitate on plates or tubes of opposite polarity.	Confined usually to high temperature large volume stack gas cleaning.
Cupola Wet Cap	A chamber in which gas is turned and passed through sprays.	Cupola.
Venturi	Gas passed through venturi preceded by sprays injected into venturi throat and followed by entrainment separator sometimes cyclonic.	Used where wet disposal of dust is no problem or where wet reclamation is desired, or for handling explosive dusts. No secondary dust problem and ability to clean high temperature moisture laden or explosive gases.
Inertial	Dust particles thrown against wetted surfaces by centrifugal or other forces. Water distribution by nozzles, gravity, or induced air.	
Mechanical	Dust precipitated by centrifugal forces on numerous specially shaped fan blades wetted to increase efficiency.	
Orifice	Cleans by centrifugal forces, impingement, and collision of dust particles on a large body of water in motion.	

Fig. 1.

is increased, usually a smaller size will apply. Some collectors can be either partially or wholly placed outside. In extreme cases, they have been "stacked" to reduce space requirements. Space allotment figures include necessary accessories for operation of a given type.

Sensitivity to Cfm Change

A dust collector may or may not be sensitive to air volume change. If the air volume through a collector changes, both the pressure drop through it and the efficiency of its collection may change. These factors must be considered in sizing it for a given application.

Humid Air Influence

The effect of humidity on dust collectors varies with the type of collector from adverse to actual improvement. Fabric filters are usually adversely affected by excess humidity in that the dust coating on the bags tends to cake, reducing the effectiveness of the cleaning and increasing the resistance. Dry inertial and centrifugal separators may be subject to caking, bridging, and/or surface deposits. Wet collectors may even be improved since, if the air stream can be made to pass through the dew point during the collection cycle, efficiency may be improved. Collection by electrical precipitators will be improved by better electrical characteristics of the dust unless moisture is too high, when there will be a spark over.

Maximum Temperature for Standard Construction

Wet collectors are the least sensitive to elevated temperatures because of the cooling effect of the water. Inertial and cyclone separators are medium in their range usually operating up to 750° except for mechanical cyclones which have a heat transfer to bearings problem similar to a fan. Electrical precipitators usually operate up to 500°. Fabric collectors are limited to heat resistance of the material in the bags which ranges from 180°F for cotton up through wool, and the synthetics to glass fiber at 560°F.

Water Requirements

Wet collectors vary in their water requirements. Some collectors such as the orifice types employ a great deal of water. Most collectors can use recirculation systems with settling systems where the only water usage is the net evaporation. Others use only small amounts such as the wet mechanicals, but the water is not usually reused.

Advantages, Disadvantages, and Limitations of Control Equipment

The advantages, disadvantages, and limitations of control equipment fall into groups the same as the characteristics listed above. These groups are: (*1*) inertial and centrifugal separators; (*2*) fabric filters; (*3*) electrostatic precipitators; and (*4*) wet collectors.

Inertial and Centrifugal Separators

The advantages of this group are listed as follows: (*1*) can be used in high temperature service; (*2*) low initial cost; (*3*) relatively simple construction; (*4*) continuous disposal of collected material; (*5*) relatively low maintenance cost if no abrasion problem, and (*6*) for the mechanical cyclones, small space requirements.

The disadvantages are: (*1*) cannot handle tacky materials and (*2*) abrasion may be a problem.

The limitations are: (*1*) tendency to plug in presence of moisture; (*2*) limited collection efficiency range depending on type; (*3*) magnitude of centrifugal forces available is reduced in larger diameters; (*4*) dry disposal of collected material can create secondary dust problem; (*5*) collection efficiencies may not meet code requirements; and (*6*) for the mechanical cyclones, there is a tendency for solids to build up on the rotor or elements, causing plugging or unbalance and temperature limitations exist because of the presence of bearings, seals, etc.

Fig. 2. Approximate Characteristics of Dust Collection Equipment

(See Note F)

Equipment		Purchase Cost,[a] $ per M Cfm	Collection Range as to Particle Size, "Minimums"	Total Power Used, Hp per M Cfm	Space Requirements, Sq Ft per M Cfm	Sensitivity to cfm Change		Humid Air Influence	Maximum Temperature for Standard Construction	Pressure Drop Inches of Water	Water Requirements, Gpm per M Cfm
Classification	Type					Pressure Drop	Efficiency				
Inertial and centrifugal separators	Louvre	100/200	10–20 microns	0.1–0.2	1.0–3.0	As cfm[2]	Moderate	Note B	750°F	1–5	None
	Gas reversal	100/125	40–100	0.1	1.0–1.5	As cfm[2]	Great	Negligible	750°	0.4–1.0	None
	Low pressure drop cyclone	100/200	20–40	0.2–0.6	3.0–5.0	As cfm[2]	Great	Note B	750°	0.5–3.0	None
	High pressure drop cyclone	150/300	10–20	0.4–2.0	1.0–3.0	As cfm[2]	Great	Note B	750°	3–10	None
	Mechanical cyclone	200/300	8–20	0.5–2.0	0.5–1.0	Note A	None	Note B	Note D	Note A	None
Fabric filters	Conventional	250/400	0.25–2.0	0.5–1.5	8.0–15.0	As cfm	Negligible	Note C	180° cotton	2–6	None
	Reverse jet	500/700	0.25–1.0	0.7–1.5	9.0–13.0	As cfm	Negligible	Note C	200° wool	3–8	None
Precipitators	Electrostatic	600/1000	0.4–0.6	0.2–0.6	Large	Negligible	Great	Improves efficiency	Unl[i]mited[b]	0.4–0.6	None
Wet collectors	Cupola wet cap		50–100	None	Note E	Negligible	None	None	Unlimited[b]	0.1–0.5	3.0–10.0 Note G
	Venturi	400/800	0.1–2.0	2.0/16.0	3.5	As cfm[2]	Moderate	None	Unlimited[b]	5.0–20	5.0–10.0 Note G
	Inertial	200/400	1.0–5.0	2.0–3.0	5.0–7.0	As cfm[2]	Great	None	Note D	2–10	3.0–6.0 Note G
	Mechanical	200/400	1.0–5.0	2.0–5.0	0.5–1.5	Note A	None	None	Note D	Note A	0.5–1.5 Note G
	Orifice	200/400	1.0–5.0	2.0–3.0	3.0–7.0	As cfm[2]	Varies with design	None	Note D	3–10	3.0–6.0 Note G

Note A—May be a function of mechanical efficiency if exhauster combined with collector.
Note B—May cause condensation and plugging.
Note C—May make reconditioning difficult.
Note D—Usually unlimited. Depends on design.
Note E—Mounted on existing cupola stack.
Note F—Cost space and hp requirements based on 20 m cfm collector.
Note G—Reduced to 0.5 to 1.5 gpm if recirculated.
[a] Not installed.
[b] "Unlimited" means will handle any foundry stack temp.

Fabric Filters

The advantages are: (*1*) for the reverse jet and multiple section type, cleaning is carried out continuously or semi-continuously while air flow continues, yielding a relatively constant pressure drop and, therefore, relatively constant flow rate; and (*2*) high collection efficiency for all particle sizes even when variable flow rates and variable inlet concentrations exist, relatively simple construction and nominal power consumption.

The disadvantages are: (*1*) The conventional types are rather large and have temperature and humidity limitations; (*2*) fabric collectors tend to have high maintenance cost because of bag replacement and maintenance of rapping and control mechanisms; relatively high purchase cost; and (*4*) in the reverse jet type which uses a heavier fabric media, there is a tendency toward gradual blinding of the fabric.

The limitations are: (*1*) materials used for high temperature service or to resist chemically active gases include wool, dacron, orlon and Fiberglas. Normal temperature limits are: cotton —180°F, wool—220°F, orlon and dacron—275°F to 300°F, and Fiberglas—560°F; (*2*) cannot be used for moisture laden gases; (*3*) not recommended for explosive or inflammable gases; (*4*) dry disposal of collected material can create secondary dust problems.

Electrostatic Precipitators

The advantages are: (*1*) high collection efficiencies; (*2*) collection range covers small particle sizes; (*3*) high temperature applicability; (*4*) low pressure drop and horse power requirements; and (*5*) low maintenance and operating costs.

The disadvantages are: (*1*) quite high initial cost, especially in the smaller sizes; (*2*) possible explosion and fire hazard on some types of dust; and (*3*) large space requirements.

The limitations are: (*1*) possible unequal flow distribution; (*2*) plates will build up with certain materials such as iron oxide; and (*3*) gas velocities are limited.

Wet Collectors

Cupola Wet Caps. This type of collector has a low initial cost, but corrosion may occur in recirculation system unless water is treated to prevent acid build up. They are suitable for removal of larger particles only and may not meet all codes.

Venturi Collectors. This type provides higher efficiency with increased pressure drop and higher power costs. As in all wet collectors, the inlet air must be above 32°F and if a recirculating tank and pump are used, it must be protected from freezing.

Inertial, Mechanical, and Orifice Types. Relatively high efficiency collection of particles in the five to 10 micron range at nominal power consumption. Potentially high efficiency collection of smaller particles with adequate power consumption, moderate initial cost, and applicability for high temperature service. Wet disposal of material can lead to water pollution problems, and there can be higher power usage for higher efficiency ranges. There may be moderate to high maintenance cost due to wet corrosion and abrasion. As mentioned above, inlet air must be above 32°F and if a recirculating tank is used, the tank and pump must be protected from freezing.

10 Don't's in Selection and Application of Dust Collectors

A check list of things not to do in the selection and application of dust collecting devices should be useful. Reviewing items such as the following would save many a sour or ineffective dust collecting system.

(*1*) Don't hope to provide a dust collector by tying a burlap bag over a discharge pipe, or by directing the discharge duct into a barrel of water or a settling chamber.

Factors involved in the collection of small particles do not lend themselves to such elementary treatment. Hundreds of times each year, hopes are blasted in such attempts at the cost of dollars, man-hours, and loss of face.

(*2*) Don't put two collectors of the same order of efficiency in series. The second collector will not remove enough material to alter discharge appearance, public nuisance complaints, or settlement in plant area unless initial unit is not functioning satisfactorily.

Exceptions could include installations where agglomeration of particles are involved, or where a second collector is used to remove material concentrated in a carrier air stream from the first collector.

Fig. 3. Usual Collector Applications for Foundry Operations

Operation	Dust Emission: Concentration (See Note A)	Dust Emission: Particle Size (See Note B)	Equipment Classification: Inertial and Centrifugal Separators: Louvre Type	Gas Reversal	Low Pressure Drop Cyclones	High Pressure Drop and Multiple Cyclones	Mechanical Cyclones	Fabric Filter: Conventional	Reverse Jet	Electrostatic Precipitators	Wet Collectors: Cupola Wet Cap	Venturi	Inertial	Mechanical	Orifice	Notes (See Fig. 4)
Enclosed hood shake out	Moderate	Fine to medium											Usual	Usual	Usual	1
Side hood shake out	Light	Fine											Usual	Usual	Usual	1
Molding and core sand mixing	Moderate	Fine to medium											Usual	Usual	Usual	2
Shell sand coating	Moderate (See Note D)	Fine to medium											Usual	Usual	Usual	3
Sand reclamation dry method	Extremely heavy	Fine to medium						Frequent	Usual				Occasional	Occasional	Occasional	4
Sand handling from shake out	Moderate	Fine to medium											Usual	Usual	Usual	5
New sand handling less than 2% moisture	Moderate	Fine to medium						Occasional	Occasional				Usual	Usual	Usual	6
Core sand handling	Light	Medium						Occasional	Occasional				Usual	Usual	Usual	7
Airless abrasive cstg cleaning	Heavy	Fine to coarse		See Note C				Usual	Usual				Usual	Usual	Usual	8
Blast rooms	Moderate	Fine to medium						Usual	Usual				Usual	Usual	Usual	8
Tumbling mills	Heavy	Fine to coarse						Usual	Usual				Usual	Usual	Usual	9
Sprue mills	Moderate	Fine to coarse						Usual	Usual				Frequent	Frequent	Frequent	9
Snag grinding	Moderate	Medium to coarse	Frequent		Frequent	Frequent	Occasional	Frequent	Frequent				Frequent	Frequent	Frequent	
Swing frame grinding	Light	Medium	Frequent		Frequent	Frequent	Occasional	Frequent	Frequent				Frequent	Frequent	Frequent	
Portable grinding	Light	Fine to medium	Frequent		Occasional	Frequent		Frequent	Frequent							
Core grinding	Heavy	Medium to coarse	Occasional		Occasional	Frequent	Occasional						Occasional	Rare	Occasional	10
Cupola melting	Moderate	Fine to coarse			Occasional			Occasional		Occasional	Usual	Occasional	Rare		Rare	11
Electric furnace melting	Light	Fine						Usual	Usual	Rare						12
Brass melting	Light	Fine								Rare						13
Wood working	Moderate	Medium to coarse			Usual											14
Boiler fly ash	Light to medium	Medium to coarse	Frequent			Usual										15
Crusher	Heavy	Medium						Occasional	Occasional				Usual	Usual	Usual	

Note A—Concentration: Light—up to 1 grain per cu ft; Moderate—1 to 3 grains per cu ft; Heavy—over 3 grains per cu ft.
Note B—Particle Size: Fine—under 2 microns; Medium—2 to 20 microns; Coarse—over 20 microns.
Note C—Used as a precleaner only.
Note D—Plus explosive mixture.

(*3*) Don't visualize discharge appearance based on efficiency data. Fine particles have many, many more light reflecting surfaces per pound than coarse particles.

Appearance of effluent air will be governed by efficiency of collector, particle size of contaminant, and concentrations of solid particles. Often the removal of 85% of solids from a local exhaust system will make no visual change in the discharge stack appearance.

(*4*) Don't expect dust collection equipment design to be more advanced than productive machine design. Generally, the higher the degree of effectiveness, the more certain the need of periodic servicing, inspection, and part replacement.

Such operations will not receive proper attention where (*1*) collectors are placed in inaccessible locations without ladders, working platforms, and lighting, and (*2*) in outdoor locations where workmen are exposed to rain or winter weather.

(*5*) Don't wait for dust collectors to fail before ordering replacement parts. Periodic inspections will give ample warning. Under present-day working conditions, failure of a dust collector can mean halting production lines while long distance calls and air express shipments attempt to reduce the downtime.

(*6*) Don't expect collectors employing principles used for low efficiency primary collection to be developed that will give efficiencies equal to those of more expensive high efficiency units—hopes of the purchaser and enthusiasm of the inventor notwithstanding.

Cost to American industry of such hopes and enthusiasm each year is tremendous. Designs using centrifugal forces in a dry unit are expensive misapplications. No twist of a piece of metal will make fine dust particles forsake the laws of aerodynamic behavior.

It should be apparent that no one method or design will be suited for all industrial problems, if variation of concentration, particle size, and percentage of removal necessary are correctly evaluated.

(*7*) Don't expect replacement of exhaust air volume to slip in through cracks in windows and doors without creating cold drafts in winter months and often starving exhaust systems so that effectiveness is reduced. Makeup air supply systems can improve control, eliminate drafts, and warm the incoming outside air efficiently.

(*8*) Don't attempt to recirculate cleaned air from dust collectors handling toxic material without careful investigation of the policing required to be assured of maintained effectiveness.

(*9*) Don't install unit collectors on heavy duty production equipment operations without careful evaluation of the frequency of servicing that could be required.

(*10*) Don't expect collection equipment to function properly if hooding

Fig. 4. Notes Applying to Fig. 3—Usual Collector Applications for Foundry Operations

1 Loadings increase with metal to sand ratio and with lower moisture content of sand at time of shakeout. Smoke from burning sea coal and core binders often involved as well as steam.
2 Wet usually because of moisture vapor.
3 Wet always. Never dry and collector should be as close to preparing equipment as possible.
4 Fabric for all but shell sands, then wet to eliminate possibility of resin dust explosion.
5 Concentration of dust is a function of moisture remaining in sand following the shakeout operation. Traps or dry centrifugal collectors sometimes used to return coarser particles to sand system. Water from wet collector sometimes used at mixer to permit salvage of sea coal and bond as well as retard slurry formations in recirculated water.
6 Collection equipment for molding sand handling system can often be used for dust collection during the shorter period of new sand handling.
7 Dust problems very similar to those for molding sand system.
8 Dust problems from abrasive cleaning operations was one of the earliest in the foundry industry for which high efficiency collectors were universally applied. Airless blasting produces heaviest loads due to abraiding speed. Blast rooms where shot or grit is employed exhaust much larger air volumes for the dust released.
9 The tumbling action employed has tendency to grind or pulverize sand and scale particles, producing a substantial fraction of dust loading in low micron sizes.
10 Collectors are indicated wherever production core grinders are used.
11 Wet primary collectors on top of cupola stack used where damage to roof or excessive cost of removal of cinder accumulation is main consideration. Fabric arresters or electrostatic precipitators selected in most critical air pollution areas where visible effluent must be eliminated.
12 While wet collectors have been usual selection in the past, the fabric arrester appears the more usual selection for future installations due to its ability to provide a clear discharge. Relatively low temperatures make cost of such installations reasonable.
13 Collection of zinc oxide is receiving increasing attention where high-zinc brass alloys are melted. Fabric arresters provide high efficiency at reasonable cost where gas temperatures are moderate as from crucible, electric, and induction melting furnaces. High stack temperatures of reverberatory furnaces make problems more complex and collection equipment expensive.
14 Cyclone or dry centrifugal usual selection. Can be followed by fabric or wet collectors where recirculation of cleaned air is indicated.
15 Fly ash from boiler stacks is often overlooked by the foundry industry, but can be source of nuisance attributed to other stack discharged. High efficiency dry centrifugals provide degree of collection generally acceptable by present-day standards. High temperature and corrosive gases make better collection very expensive.

and connecting ductwork are not in accordance with good dust control practice.

Summary

As can be seen from the above, matching the control equipment available with the particular control requirement involves balancing numerous factors for both the requirement and the equipment.

We have tried to show the various pertinent characteristics for the equipment available and match them to the particular requirements found in a foundry and indicate the advantages, disadvantages, and limitations.

Collectors have been referred to by types, only, which precludes discussion of the characteristics individual to a particular manufacturer's product. These do exist and should be investigated for any given application.[1]

Fig. 5. Usual Applications by Foundry Operation

Plate III charts the various foundry operations against the various collection types.

In order to emphasize the possible pitfalls in analyzing the problems of collector application, a number of remarks are given on Fig. 4 as well as the following:

1 Shakeout operations produce light to moderate concentrations with fine to medium particle sizes with a high moisture content in the gas stream. Inertial and centrifugal separators do not have a sufficiently low particle size collection range, and if sufficient moisture is present to cause contamination, as in a hot shakeout operation, fabric collection may not apply. Electrostatic precipitators come in minimum sizes well beyond the usual volumes required which leaves us with wet collectors for this application.
2 Molding and core sand mixing also apply to the above remarks with even higher moisture contents. While it is a function of the hooding, great care should be taken to avoid loss of fines during dry additions due to excess pick up velocities.
3 Exhaust of sand resin coating processes involves loss of expensive fines, explosive vapors, and water contaminating compounds. Lower explosive limit checks should be made and wet collection should be used because of the explosive vapors and a nonoverflowing water system because of contamination.
4 Sand handling from the shakeout involves high moisture contents and elevated temperatures. Cold drafts will create excess moisture conditions and sand deposits in the ductwork. Excess exhaust does little to correct this.
5 Airless abrasive and tumbling mill casting cleaning gives very high dust loadings. There is also a tendency to "slug" the collector at the beginning of the cycle. All types of casting cleaning and especially casting grinding involve particles of iron and iron oxide. These materials tend to "cement" in the presence of moisture and can cause plugging of filter fabrics, build up on wet collector surfaces; especially in areas between wet and dry spots, and plug slurry lines if adequate velocities are not maintained. All of the cleaning and grinding operations involve highly abrasive dusts which may cause excessive wear in collection devices.
6 Collection from melting operations involves high temperatures, varying quantities of gases and dust loadings, and a wide range of particle sizes.

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(*Continued on p 259*)

Atmospheric DISPERSION *Over* LONGER *Travel* DISTANCES*

GLENN R. HILST, Ph.D., Assistant Director, Weather System Division,
The Travelers Insurance Company, Hartford, Conn.

The problem of atmospheric dispersion of airborne materials as they are transported over distances of the order of tens of miles is set, in a practical sense, by the consideration of potential hazards in the vicinity of unusually large or critical sources and in the cumulative effects of multiple sources. At this scale of length (and travel time) we are intermediate between the practical problems of air pollution in the immediate vicinity of a single source or a close cluster of several sources, and the more colossal scale of continental or global lengths and the massive sources, such as volcanic eruptions or nuclear detonations which make these latter scales of length important in the context of atmospheric pollution. The practical problems of air pollution on the scale of tens of miles is much more akin to the very small scale problems, however, primarily because of an increasing need for more and more precise determinations of the distributions of pollutants. On the continental or global scale we may consider gross averages over large areas and relatively large lengths of time. In the small and intermediate length scales the practical problems of design, operation, and protective action require consideration of space and time variations of a much more sophisticated and precise kind.

Consider, for example, the case of a single source which could produce sufficient airborne material so as to constitute a major hazard to the environs. In particular, we wish to estimate the potential losses in the surroundings given the magnitude and mode of release of the contaminant. Any prediction system which yields only an order-of-magnitude estimate of the resulting dosage to the surrounding area is of questionable value since, for example, the difference between 10^6 and 10^7 dollars may very well be the difference between an acceptable and an unacceptable risk. Major decisions with regard to site selection, plant design, expenditures for safety and air cleaning equipment, etc., hinge upon such estimates—to say nothing of the more basic "go" or "no-go" decisions which may be ultimately controlled by environmental liability considerations.

The Meteorological Problem

Recognizing, then, the need for precise information on the distributions and effects of air pollutants, what is the present state of knowledge regarding the meteorological phase of this problem? What do we know about the atmosphere's capacity to transport and dilute airborne materials over travel distances of the order of tens of miles? It is not unduly pessimistic, nor is it an unwarranted plea for additional research funds, to say our knowledge in this area is woefully inadequate. We do know some things but quantitative information is scarce and almost always highly restricted to special meteorological-terrain conditions.

Observations of the decrease of concentrations along the mean centerline of a plume originating at a continuous ground source and over distances of one to eight miles have been reported by Hilst (1959)[1] based on measurements made at the Hanford Works. These data, while far from complete in defining the distributions of the tracer material, do provide a first assessment of the variabilities of concentrations or dosages due to variations, in meteorological conditions. Stated briefly, these measurements showed that, at a given distance, beyond one mile from the source, the average concentrations in stably stratified atmospheres were at least 1000 times greater than in unstable temperature stratifications and this range of values appeared to increase with increasing distance from the source. Although they could not be separated out, the effects of nonuniform wind velocity and deposition are included in these results.

The reduced diffusion rates which are encountered in stably stratified atmospheres are well known; the enhanced dispersion due to organized convective motions of appreciable vertical depth in unstable temperature stratifications has not been well specified, however, due to the need for extensive sampling through several thousand feet of depth of the atmosphere. The results quoted above begin to provide a quantitative assessment of the effects of this meteorological variability. Clearly, the immediate hazard in the vicinity of a ground source is several orders of magnitude greater, for a given source strength, in the night time temperature inversion situation. This fact, coupled with concern for proper evaluation of extreme values of environmental hazards, resulted in the conduct of a joint AEC-AF program at Hanford during the summer of 1959 in which very intensive measurements of airborne concentrations of tracer materials emitted into stably stratified atmospheres were measured at distances up to 16 miles from the ground source. These data will provide much improved estimates of areal dosages and atmospheric dispersion capacities for the distances of interest here and for the critical case of stably stratified atmospheres.

Inherent to the problem of estimating the distribution patterns of airborne contaminants is the problem of determining the trajectories of materials in the presence of variable wind fields. The detailed studies of trajectories within the Los Angeles Basin reported by Neiburger (1956)[2] showed that material emanating from a source at different times, separated by as little as an hour or two, may proceed to widely diverse points of the Basin. These divergent trajectories reflect both the large-scale, dynamically induced, variability of wind direction and the channeling of air flow which are caused by significant terrain irregularities.

Certain relatively simple combinations of terrain features, such as a simple valley and plain, and adjacent sizable bodies of water and land, permit specification of expected diurnal wind variations and channeling effects. In real situations the terrain irregularities are

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generally sufficiently complex as to prevent prior assessment of probable contaminant trajectories. In such cases, our only recourse is to direct measurements using tracers such as smoke, SO_2, fluorescent pigment, fluoresceine dyes, etc. These are time consuming efforts, particularly if sufficient data are to be gathered for reliable statistical assessment of probable or expected trajectories.

The basic features of atmospheric dispersion patterns over distances of the order of tens of miles can be deduced for simple meteorological-terrain combinations. These estimates deteriorate quickly as the complexity of the terrain increases. However, serious as this limitation is in real problems, an equally serious deficit in our present knowledge is a lack of information on the removal of contaminants by deposition and wash-out and the proper allowance for nonuniform meteorological effects over longer times and distances.

In the very small-scale dispersion problem it is generally admissible to assume a uniform, steady mean wind velocity, uniform terrain, and statistically stable parameters of the turbulent motions. Under these conditions the dispersion equations can be solved for the steady-state average concentration distribution, and useful quantitative results can be derived from these equations. At the scale of tens of miles these simplifying assumptions are almost always manifestly false in the real atmosphere and lead to serious errors of estimate. Over these distances the wind velocity is seldom, if ever, steady or uniform even in the average. The turbulent components of motion, dependent as they are upon surface roughness, uneven surface heating or cooling, and local stability criteria, may also vary appreciably over the path length. And, finally, major variations in terrain or ground cover, or the diurnal variations in temperature structure and wind fields, which may occur during the transit time of the material over the distance of interest, thoroughly confound the solution of the dispersion equations.

Extreme precision in the specification of concentration distributions, in the sense of fine time resolution, and micro-patterns within the larger scale patterns, can hardly be expected. The primary difficulty now is the lack of published data which are comprehensive enough to define the magnitude and variability of even the more gross features of these patterns. Our present assessments of the effects of terrain and meteorological variabilities and the loss of materials by deposition and precipitation scavenging are based on very meagre data. Hopefully, recent experiments, such as the AEC-Air Force program at Hanford, will partially overcome this deficit soon. Many more data from other terrain, meteorological, and material situations are clearly required, however, if a systematic evaluation of these effects is to emerge.

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High Temperature FABRIC FILTRATION *of* INDUSTRIAL GASES*

PAUL W. SPAITE, DAVID G. STEPHAN, and **ANDREW H. ROSE, JR.,** Engineering Research and Development Unit, Air Pollution Engineering Research, Robert A. Taft Sanitary Engineering Center, Division of Engineering Services, Public Health Service, U. S. Department of Health, Education, & Welfare, Cincinnati, Ohio

The industrial application of fabric filtration of gases was limited for many years by the low thermal resistance of organic filter media; filtration temperatures were restricted to below about 275°F. The introduction of silicone finished glass fabrics just over 10 years ago effectively doubled this limit, and glass fiber material remains today the only commercially available fabric in general use for high temperature gas filtration. The present paper attempts to assess the field of industrial filtration over 300°F in a general way, but historically it tends to be dominated by considerations related to fiber glass. Other high temperature media (asbestos, fluorocarbons, silica, aluminum silicate, etc.) are not discussed because they do not appear to offer as great a potential for widespread industrial use in the immediate future.

In terms of thermal effects at temperatures over 300°F, filtration may, from a practical standpoint, be classified in three temperature ranges: 300–550°F, 550–750°F, and over 750°F. Between 300° and 550°F, glass fabrics are satisfactory for many applications. Large-scale filtration has been successful in this range, and the problems encountered have resulted chiefly from lack of experience with the basically different glass medium. Industrial applications are increasing and should lead to fairly rapid accumulation of information and a reasonably prompt elimination of major problems.

In the range 550–750°F, available glass fabrics are generally not satisfactory for continuous filtering duty, because of loss of abrasion resistance within the glass fabric. Present fabrics would probably be satisfactory in this range if suitable lubricants or finishes are developed. Glass filter fabrics in use in this range and even higher are often mentioned, but the temperatures are incompletely defined or refer specifically to the inlet gas rather than the filter. Gas streams entering a conventional filter installation can be much hotter than the filter fabric itself, and it appears unlikely that fabric temperatures in excess of 550°F occur in any existing baghouse-type installation.

Operation over 750°F would probably require materials and equipment designs appreciably different from those currently in use. In addition, because of increasing power requirements, justification for filtering gases in this range would have to be unusually attractive, and filtration above 1000°F probably could not be justified except under special circumstances.

Inasmuch as these temperature limits are not always clearly defined, and since heat effects are not unique to a single range, the subsequent discussion will be divided as follows: 1) thermal effects on equipment, 2) thermal effects on media, 3) thermal effects on chemical attack, and 4) thermal effects on power requirements.

Thermal Effects

Thermal Effects on Equipment

Every increase in temperature at which gases are filtered gives rise to new equipment design considerations. In the 300–550°F temperature range, a variety of differences in design from conventional, lower temperature filters have developed; most have been inspired by the relatively poor flex and abrasion resistance of glass fabrics. Such changes as increased bag spacings, modified bag mounting techniques, use of spring suspended bags, and replacement of tented bag tops with bag caps have been made. By far the most important modifications have related to filter cleaning where a number of new techniques—bag collapse, use of sonic energy, redesign of shaking mechanisms —have been introduced.

Collapse cleaning has found wide acceptance where glass media are employed. It involves a physical collapse of the cylindrical filter bag induced by the application of a slight reverse pressure differential across the filter. No large reverse flow of air is required, but cake is removed by the flexing of the bag as it deflates (usually into a four-pointed star cross-section) and reinflates.

Either sonic energy or mechanical shaking is sometimes used in conjunction with collapse cleaning. Sonic energy, generated by a "horn" mounted within the filtering compartment, can be applied for several seconds while bags are in a collapsed or semi-collapsed condition. Manufacturers of this device report[1] that residual pressures can be reduced to 50% of those obtained in collapse alone. Also, it is possible to use collapse cleaning for a number of cycles consecutively with only occasional mechanical shaking. This technique has been used where relatively hard to clean dust-fabric combinations are encountered.

The fairly gentle cleaning techniques mentioned above have been possible largely because of the good release characteristics of silicone-finished glass. On the other hand, this ease with which a dust cake can be removed from glass fabric introduces a concomitant problem, a tendency to bleed or lose efficiency with increasing filter velocities. Partly because of this, average filter velocities through glass are usually held in the 1.5 to two fpm range rather than at the three fpm common in low temperature fabric bag practice. A possible solution to this lies in the use of fabrics woven with "bulked" glass yarn in the fill direction. These yarns, which are of the continuous filament type but "fluffed" by passage through high velocity air jets, provide a rougher, nubbly surface to the fabric which gives promise of high efficiency, high permeability operation without loss of desirable strength and release characteristics.

Other mechanical design problems arise simply as the result of high temperature service requirements for structural and mechanical parts. For example, plug-type dampers have replaced butterfly dampers on some installations, shaker bearings have been moved outboard, and wall insulation may be required to prevent con-

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densation. Problems of this type become much more complex as working temperatures increase: Thus, carbon steel construction becomes less practical in the 750–1000°F range, warpage and thermal expansion of various parts become of increasing concern, and other general difficulties associated with high temperature operation of equipment are introduced. These complications are sufficient that possible application of fabric filter equipment at such temperatures seems remote.

Thermal Effects on Media

The effects of thermal exposure on the physical properties of glass fabrics are dependent on time and temperature, and are complicated by the fact that the time-temperature effects on both the finish and the basic fibers must be considered simultaneously. It is generally believed that glass fabrics fail because of abrasion between individual fibers of the cloth, but few theories relating to methods of protection against this failure enjoy universal acceptance. Experimental data pertaining to the mechanism of failure are limited. Results available from bench-scale testing indicate[2, 3] that flex life and tensile strength of silicone-coated fabrics decrease gradually as temperatures are increased to the 500°F range. This decrease of strength accelerates until at about 600°F it appears that some critical limit has been passed so that failure is quite rapid. This phenomenon has been assumed by many to be evidence of failure resulting from destruction of the silicone finish so as to permit fiber-to-fiber abrasion within the cloth.

A second point, also relative to the mechanism of failure, on which expert opinion differs is the extent to which glass fabric failures are attributable to loss of fiber strength because of thermal exposure in service. The extremes of opinion are represented by two schools of thought. One holds that the current commercial heat-cleaning operations to remove the starch-oil size applied to protect the fibers during weaving will "relax" the glass to a degree that precludes any further weakening at working temperatures currently in use or foreseen for the near future. This group feels that the solution to immediate problems can be found in more stable lubricants. The other school holds that commercial glass textiles are significantly weakened by exposure to operating temperatures, even in the 500° to 650°F range. Since this weakening may contribute substantially to shorter fabric life in industrial usage, it is felt in these quarters that development of new finishes might improve performance but will not provide the complete answer to problems that are encountered when filtration temperatures approach 750°F.

This divergence of opinion is not unreasonable, since the properties of a glass fabric are a complex function of its total thermal history. Prediction of the behavior of a fabric in service involves estimating the net effect of each heat exposure it receives during its fabrication, treatment, and use. In fabrication the drawing of fibers from the molten state involves a rapid chilling which locks in internal stresses that tend to relax when the fibers are reheated, as for the heat-cleaning operation at 600° to 1300°F. This second heating thus serves two purposes: (*1*) volatilization of the size applied for protection during weaving, and (*2*) relieving of some of the internal stresses. This produces observable increased flexibility of the cloth and semipermanent deforming of the individual fibers to fit the weave pattern. Also, heat-cleaning is known to reduce the mechanical strength substantially, so that speculation has arisen as to the feasibility of using nonheat cleaned cloth (greige goods) directly, thereby retaining much of the original fabric strength. One source reports that several bags fashioned from greige goods and installed in a cement kiln filter operated for at least six months without failing. Others have suggested that silicone coatings can be applied directly to greige goods without any adverse effects on the protective coating when the size is subsequently volatilized by exposure to operating temperatures. This approach to application of the silicone has been reported successful on a bench-scale,[2] but no claim is made that fabric so treated will perform as well as or better than conventionally treated commercial fabrics, since it is recognized that heat treatment may produce other basic changes in the glass which are essential to satisfactory operation.

In spite of the existence of textile testing procedures and equipment and data therefrom, no correlations have been developed between results from such tests and actual performance of a fabric in filtering service. Nevertheless, laboratory data available lend considerable support to the belief that glass media should provide adequate filtering performance up to at least 750°F if abrasion of fibers is reduced by lubrication or other means.

Thermal Effects on Chemical Attack

Increased rates of chemical reaction and new types of corrosive attack must be considered in the operation of high temperature equipment. Media problems, for example, become associated with attack on inorganic fibers and on textile finishes so that past experience with low temperature organic media cannot be extrapolated to predict performance.

Perhaps of greatest concern in this respect are the fluorides often encountered in emissions from high temperature industrial operations. Compounds containing fluorine are found in association with numerous minerals. They may be introduced to a process directly with raw materials or added with fluxing agents. Fluorides may be evolved in either gaseous (HF, SiF_4, BF_3) or particulate form (fumes from volatilization of metallic fluorides). Semrau[4] has shown that gaseous HF is often the most probable form. Fluorides can attack glass at any temperature from ambient upward, but the severest corrosion occurs in the presence of moisture. Rates of attack on glass textiles at various temperatures have not been reported, but it is possible that such corrosion may decrease at temperatures above 500°F, where chemical equilibrium is shifted back toward SiO_2.

Several techniques have been used to decrease fluoride content of process effluents, primarily to minimize fluoride pollution but also to protect control equipment from chemical attack. Granular limestone, for example, has been added to the feed mix at a steel plant sinter line to accomplish a 50% reduction in fluoride content of the effluent.[5] Also, finely pulverized limestone or calcium hydroxide has been injected into gases prior to filtration or used as a filter precoat to convert gaseous fluorides to less chemically active solid fluorides, thereby reducing attack on the fabric filter.

Chlorides and sulfur oxides are reported to have little direct effect on glass under 1000°F, but a possible complication is the reaction of SO_3 and SO_2 with various metal parts to give metallic sulfides and sulfates which crystallize into abrasive particles. Also, steam can react with glass at elevated temperatures and fibers should be especially susceptible. Unfortunately, no data on this type of attack in filtering service are available at this time.

It is reasonable to expect that surface finishes on fabric media could provide some protection against corrosion. Some believe that silicones currently used on glass should inhibit attack by steam but should not provide a shield against fluorides. Fluorocarbon finishes, if economically feasible, might provide the key to fluoride protection at temperatures below 475–500°F. More information should be obtained, however, regarding the possibility of attack on the glass by products of thermal dissociation of these finishes.

A problem with processes that evolve alkali fumes is the effect of these

materials on glass. Cement kiln gas, for example, contains varying quantities of volatilized alkalis that will condense out as solid particles if filtration temperatures are low enough. At one cement plant installation these materials condensed out as small crystals on the outside surface of glass filter bags, producing increased residual filter pressures but no observable corrosive attack. The crystals, which were water soluble, could be washed off. Filter operation at a slightly higher temperature eliminated this problem.

Thermal Effects on Power Requirements

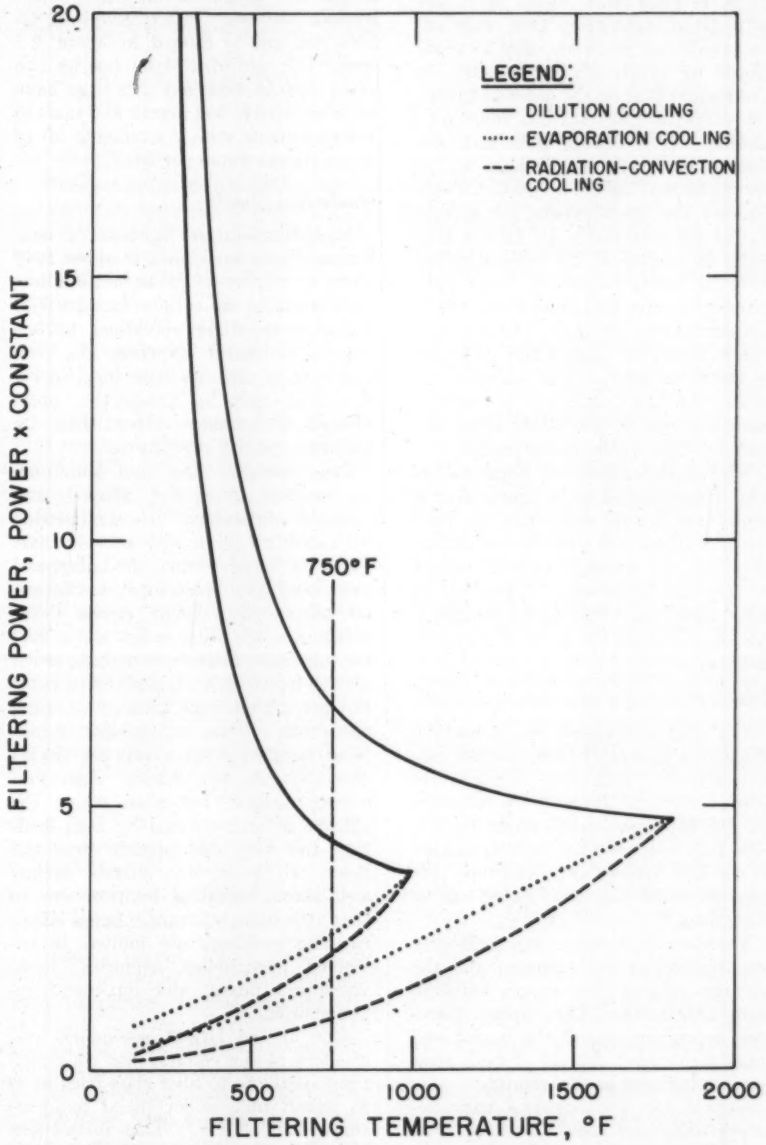
The power required to pump gases through a flow system is proportional to the product of the volume of gas flowing through the fan and the system pressure drop. For a given mass flow rate, volume flow increases directly with the absolute temperature as does pressure drop for turbulent flow conditions. For viscous flow, which will occur through the filter medium itself, the increase in gas viscosity with temperature is also important, and pressure drop becomes roughly proportional to the square of the absolute temperature. Therefore, filtering power requirements will increase with filtering temperature. Power is, however, only one factor in a complex economic balance in which power costs and other expenses associated with high temperature operation must be weighed against the costs involved in cooling the gas stream.

Industrial gas cooling may be accomplished by three basic mechanisms: radiation-convection, evaporation, and dilution. Figure 1 shows the changes in filter power requirements which result from cooling hypothetical effluent streams from either 1800°F or 1000°F to the temperatures shown along the abscissa. The three curves originating from each point illustrate the differing effects on power resulting from cooling by each of the three mechanisms independently.

It can be seen that filtering power requirements for an effluent stream will increase only gradually as the gas is cooled by simple air dilution down to as far as 750°F while cooling by either evaporation or radiation-convection over the same range will result in rapid decreases in power required. Even though dilution cooling is the most extravagant method from a power standpoint (cooling by either radiation-convection or evaporation will not add significantly to the total mass being handled), the increase in power which would result from adding the required mass of diluent air is nearly canceled by reductions in both viscosity and volume of the effluent when it is cooled from elevated temperatures to 750°F. For this reason, cooling to the 750°F range will never require more than a relatively small increase in power over that required for filtration at 1000°F or higher.

This conclusion is conservative in that it is based on the assumptions that (*1*) gas flow is viscous both through the filter medium and through the remainder of the flow system (consideration of turbulent flow will yield lower power values), and (*2*) dilution cooling is accomplished in the absence of radiation-convection heat transfer. Since dilution cooling will never be found without some radiation-convection heat transfer being superimposed, dilution cooling curves represent theoretical maximum power boundary conditions which will never actually be reached. Under operating conditions, cooling curves will fall somewhere between those shown for dilution cooling and those for radiation cooling.

In practice, therefore, it is likely that power requirements for filtering gas cooled to the 550° to 750°F range will be of the same magnitude or below those for filtering the uncooled gas stream. Hence, where process requirements do not dictate filtration at higher temperatures, and where heat recovery from the effluent stream is neither



CHANGES IN FILTERING POWER REQUIREMENTS WITH COOLING OF EFFLUENT STREAM

Fig. 1.

economical nor desired, there appears to be little incentive for filtering gases above 750°F.

Current Status

Currently about 100 full-scale high temperature fabric filter installations are in use in the United States. Units range in size from a few handling less than 5000 cfm, to large units, capable of handling several hundred thousand cubic feet per minute. Most units have capacities between 50,000 cfm and 250,000 cfm. Installed costs for high temperature filter facilities will generally fall between $1 and $2.50 per cfm exclusive of gas cooling equipment. Prices for glass fabric media vary, but for a given installation first costs for glass media are generally close to those quoted for synthetic fiber media. It is estimated that on the order of 1,000,000 yards of glass textiles went into filtering service during 1959 and predictions of future usage range up to five times that figure by 1965. Table I shows the specifications for several typical filter fabrics. All fabrics currently in use are of the same nominal chemical composition (a low soda content lime-alumina borosilicate glass) and are silicone coated. The oils currently offered for glass textile finishing by the three producers of silicones are either dimethyl siloxanes or phenylmethyl siloxanes, the latter being the more resistant to thermal exposure.

While high temperature filtration has been demonstrated to be practical in a number of major industries, in only one application, the collection of carbon black, has the potential been developed to near its maximum. Expansion in other areas could very likely produce a rate of growth on the order of that predicted.

Gray Iron

The gray iron cupola is a prime example of a particulate source which can be controlled with high temperature fabric filtration. Roughly ten years ago the first baghouses with silicone finished glass bags were installed on iron cupolas in the Los Angeles area, and now perhaps 20 cupolas in that region are so controlled.

There are now more than 3200 gray iron cupolas in this country, and the average effluent per cupola is more than 15,000 cfm. The cupola, therefore, represents one of the largest and most widespread sources of high temperature effluent in this country.

Cupola top temperatures vary between 1000° and 2200°F with an average effluent loading of about 1 grain/ft.[3] Much of the emission is fine metal oxide fume less than 0.5 micron in diameter. In those situations where high temperature fabric filters are employed, gas cooling is necessary and evaporation cooling is by far the most common technique. Off-gas temperatures are reduced to about 450°F for filtration through bags which are usually 11½ in. in diameter by 15½ ft in length and which are cleaned by mechanical shakers. In a typical installation, the gas is filtered at about 2.5 fpm. Bag life of at least one or two years can be expected and bags have been reported to last four or five years in noncontinuous service averaging 20 to 40 on-stream hours per week.

Table I

Thread Count	Weave	Weight, Oz/Yard	Permeability, Cfm	Yarns Warp	Yarns Fill
54 × 54	Crowfoot	9.5	10–17	150½	150½
64 × 60	Crowfoot	12.0	8–12	225½	150½[a]
48 × 22	Crowfoot	17.0	45–60	150½	31½[b]

[a] "Bulked" continuous filament yarn in fill.
[b] Staple yarn in fill.

Nonferrous Metals

High temperature filtration of nonferrous fumes dates back to about 1949 when a number of glass fabric filters were installed on various foundry and secondary smelting operations in Los Angeles. Interest elsewhere has been more recent and has been inspired for the most part by prospective operational advantages rather than by pollution control regulations.

Lead, copper, zinc, and aluminum are smelted, recovered, alloyed, and founded separately, in combination with each other, or with other metals. The exact combination, the equipment used, and the operational techniques all affect the effluent stream. Gas volumes range from a few cubic feet per minute in nonferrous melting crucibles to hundreds of thousands of cubic feet per minute from primary smelting operations. From an emission standpoint, nonferrous operations are divided generally into two classes: those producing metallic fumes in which the effluent is characterized by high loadings and very fine particle size, and those which involve metals boiling well above operating temperatures so that little fume is formed. In the latter, cleaning problems are limited to entrained particulates, unburned fuels, volatilized fluxes, and flux-metal reaction products.

One of the largest secondary lead smelters in the country has converted from synthetic to fiber glass bags so as to permit fume collection at temperatures over 400°F. This installation cleans the combined effluent from a reverberatory furnace and a lead blast furnace. Higher filtering temperatures were desired in order to eliminate the deposition of organic tars on the bags. After sixteen months experience with fiber glass bags, operating at 1.2 fpm and cleaned by shaking, results are reported as satisfactory.

After pilot-scale studies with both synthetic and fiber glass media at an integrated smelter producing primary copper and zinc, a baghouse equipped with 222,000 sq ft of glass fiber media was constructed in 1957 to clean the effluent streams from a reverberatory furnace and copper converters. Glass fabric was selected because of its corrosion resistance and because operation at 450°F reduced by roughly 50% the radiation-convection heat transfer area which would have been required for cooling to temperatures safe for organic media. The average filter ratio is 1.6 fpm and bags five inches in diameter by 10 ft long are used. Bag cleaning involves collapse every one-half hour supplemented by mechanical shaking every eight hours. Recently sonic cleaning equipment has been tried experimentally. Based on present knowledge, an average bag life in excess of two years is anticipated.

Perlite

Perlite, a volcanic glass mined in the western United States, is processed in furnaces of various design in 85 plants in the United States. Temperatures of 1500° to 2000°F are used to convert moisture inherent in the ore to steam, so that it expands the raw material to a porous, cellular, lightweight aggregate. Expanded perlite is often conveyed from the furnaces pneumatically and passed through cyclone collectors for product recovery. Dusty off-gases, usually less than 10,000 cfm per furnace, are controlled by high temperature glass filters in three or four of these plants. Five- or six-inch diameter bags about 10 ft long and cleaned by mechanical shaking are used. Filter velocities average less than 1.5 fpm and bag life is reported to be at least one year.

Carbon Black

The production of carbon black involves the combustion or thermal cracking of hydrocarbons such as natural gas or petroleum in an atmosphere deficient in oxygen. Very fine particles of carbon are formed and the effluent gas is cleaned to collect the

product. The collection equipment is generally a tertiary system consisting of some combination of electrostatic precipitators, cyclones, scrubbers, and bag filters.

Baghouses equipped with glass fiber bags are reported to be used for the final cleaning in about 90% of the 50 carbon black plants in active production in the United States. Earlier baghouses used synthetic bags, but the necessity of holding filtration temperatures to below 250°F to protect the media created a problem, since this temperature, especially with the evaporative cooling employed, is close enough to the "acid dew-point" to cause serious corrosion. Following the introduction of glass filters to this industry in about 1953, this problem has been minimized by operating at temperatures of 400° to 500°F. Bag collapse with some supplementary shaking is the most common cleaning technique. The bags in use in this industry are commonly five inches by $11^1/_2$ ft with filter velocities held to 1.5 fpm. The average baghouse capacity is around 50,000 cfm and bag life generally expected is 12 to 18 months.

Cement

At the present time at least 17 cement plants (roughly 10% of the total) in the United States are now operating full-scale filters for the control of both wet- and dry-process kiln off-gases. The acceptance of these units by the cement industry stems largely from the $2^1/_2$-year successful operation of a prototype filter on a wet-process kiln in southern California. During pilot testing at this location in 1956, the feasibility of the collapse-cleaning technique for cement dust was discovered. Results of these pilot tests provided such encouragement that a full-scale prototype unit to handle all effluent from a 2400 bbl/day kiln was designed and constructed. Operation of this unit since October of 1957 with only a single 3 to 4 hour shut-down per month (necessitated by kiln maintenance) has provided ample proof that such filters are capable of continuous, high-temperature use.

This unit, typical of those in the cement industry, contains $11^1/_2$-inch diameter by 25-ft long woven glass tubes arranged in 12 compartments of 48 bags each. Over 90,000 cfm of gas at just over 500°F are handled. The average filter velocity for this unit is 2.1 fpm based on inlet temperature and resulting ΔP is very close to three in. H_2O. No significant increase in residual pressure drop has occurred since the filter went on stream. Filters are cleaned by bag collapse at 60-minute intervals. During the first nine months of operation, only 16 of the 576 bags had to be replaced, and in each instance, failure was attributable to some extraneous mechanical damage.

Two large-scale filters are now being operated in Pennsylvania, and a third is going into operation in the near future, in which sonic energy is employed in conjunction with bag collapse to clean cement kiln dust from glass filters. Bag replacement during the first nine months of operation of the two existing units has been reported to average only 0.5% per month.

The fact that no stack is required where low sulfur-content fuel is fired is another advantage of high temperature filter application. At least two new cement plants have been put on stream within the last year for which stacks have not been constructed because of the employment of kiln effluent filtration.

Electric Arc Steel

The electric arc steel furnace presents an emission control problem which is characterized by fine particulate with high oxides of iron content, dispersed in a gas stream that is highly variable in temperature, loading, and volume during the different process cycles. Effluent volume is dependent on the type of hooding arrangement employed since the dilution air flow is adjusted to provide for gas cooling and in-plant dust control. Stack temperatures may reach 750°F or higher with closely hooded units.

During mid-1958 a pilot-scale filter using glass bags and operating between 350° and 500°F was tested at a Seattle steel plant. Following this evaluation, a full-scale high temperature unit was put into operation, and is believed to be the first large-scale glass filter installation in the steel industry. This unit handling 105,000 cfm at temperatures up to 500°F has been on stream for over a year with no noticeable deterioration of the fabric and no increase in residual pressure drop. The $11^1/_2$-in. by 25-ft filters which operate at a filter ratio of 1.8 are collapse-cleaned.

Other Installations

Full-scale fabric filters have been reported in use in other high temperature operations which include: (*1*) collection of aluminum chloride formed by fluxing aluminum with chlorine, (*2*) removal of talc dust from a carrier gas of superheated steam, (*3*) control of emissions from a boric oxide fusion furnace, and (*4*) control of a sodium phosphate kiln. Details relating to these operations were not readily available and they are mentioned only to complete the listing of known high temperature industrial filter units.

Future Prospects

Potential Applications

Even now, pilot-scale testing of high temperature fabric filters is under way on several new applications. At least three pilot units are being evaluated for open hearth control, two on oil-fired power plant boilers, another on a municipal incinerator, and still another on a steel plant sintering operation.

The steel industry is especially anxious to see the development of more effective controls for open hearth furnaces; interest is also high with regard to sinter plant emissions. Perhaps the biggest uncertainty in the filtration of both these materials is the effect of fluorides on currently available glass media. Hopefully, results now being obtained will provide this information. Tests on filtration of oil-fired boiler fly ash are directed toward gathering sufficient design data for an economic comparison with electrical precipitators. Engineers conducting these studies believe that high temperature filters can provide a solution to the problem of power plant stack plume opacity. Objectives of the incinerator pilot tests are also to gather design data for a full-scale unit. Of especial interest here are ramifications of highly variable particulate loadings and stack temperatures and the effects of frequent shut-down and start-up operations.

Results from the above studies have been generally satisfactory to date, but a number of potential problems must be evaluated and design criteria established before widespread use of filter equipment can be expected in any of these areas. As the store of knowledge and experience relating to filtration at elevated temperatures grows, and concurrently the need for more stringent pollution control increases, fabric air filters will undoubtedly come into wider use. Applications which have been suggested include oxygen steel converters, ferromanganese blast furnaces, pulverized coal-fired boilers, scarfing mills, lime kilns, asphalt plants, catalyst recovery units, fluidized coking operations, glass furnaces, chromite ore kilns, and electric furnaces used for calcium carbide and phosphorus production.

Research

Expanding interest in high temperature filtration has provided the impetus for research in certain areas. Improved and more stable finishes are under development. Improved glass textiles and new high temperature fabrics developed for other uses are being evaluated as filter media. Current studies of filter cleaning and of the fundamentals of filtration through tu-

(*Continued on p 259*)

GOVERNMENT *Sponsored Air Pollution* RESEARCH RELATING *to* AGRICULTURE*

C. STAFFORD BRÅNDT,† Chief, Agriculture Liaison Unit, Air Pollution Engineering Research, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

Early Efforts

The first major air pollution problems affecting agriculture in this country arose at the turn of the century as a result of fumes from smelters. The federal government became seriously involved in these problems, particularly in the west. The first reports published in this country on research into the smelter fume injury to vegetation were those of Haywood from the Bureau of Chemistry of the United States Department of Agriculture.[4, 5] While most of the problem areas around the western smelters were not as dramatic as the now famous smelter at Ducktown, Tenn., there was no question that both agricultural crops and forests were being injured. In certain of the areas there were also cases of cattle poisoning by arsenic from the smelters.

The gross effects of sulfur dioxide upon vegetation were reasonably well known. European smelters had been faced with this problem for many years. The publications of workers in these countries, particularly the handbook of Haselhoff and Lindau,[3] were certainly available. The investigators from the Department of Agriculture and other agencies were not held in very high esteem although they were doing little more than translating and confirming these accepted European observations. It must be remembered that the federal government was the plaintiff in several of the cases, seeking an injunction against specific smelters. Some of the intensity of the feeling against the "bureau experts" can be gained from the reports in the local papers and the mining trade journals of the time. Some of these reports have been abstracted in a bibliography of air pollution published by the Bureau of Mines.[2] In one abstract, reference is made to "the blundering interference with the Mining Industry by immature officers of the Forest Service." In time, however, compromises were made and the major conflicts of interest were reconciled. With the issuance of the report of the Selby Smelter Commission by the Bureau of Mines in 1915,[7] the federal government suspended interest in air pollution as it affected agriculture. Some 12 years later, however, the government again became deeply involved in a smelter problem.

In 1896 a smelter had been built on the Columbia River at Trail, British Columbia some 10 miles from the international boundary. Over the years it had grown slowly and steadily into an important and sizable industry. Then the farmers in the upper Columbia River Valley on the Washington side of the boundary began to make claims for damages from sulfur dioxide fumes arising from the smelter. The company settled most of the complaints, and this practice continued for two or three years. However, in 1927 the farmers and property owners requested the intervention of the federal government in pressing their claims against the smelter. As a result, the case was referred to the International Joint Commission under the provisions of the Boundary Waters Treaty of 1909. Both governments established teams of scientists to investigate and report to the Commission. The Canadian government worked through the National Research Council of Canada and the United States government worked through the Department of Agriculture. The mining company established a third independent team of scientists drawn from both sides of the border. This was certainly the most thoroughly investigated air pollution incident to date. After some three years of investigations the International Joint Commission issued its report in 1931. Since the report was not fully acceptable to the United States interests, and since there was alleged continual damage to the vegetation of the area, the case was reopened and referred to an international tribunal in 1935. This required further investigations.

The approaches used by both sides were similar: field survey, supported by air monitoring and meteorological data, and field trials with specific crops within the fume area, supported with artificially fumigated material. It is of interest to note that while the investigations by the United States group were never published in their entirety except in the proceedings of the commission and tribunal, the investigations of the Canadian group were published in a full report.[11]

Present Efforts

While early experiences were less than satisfactory, within recent years there has been federally supported research in the agricultural aspects of air pollution. It will be convenient to review this work on the basis of the nature of the support: (*1*) research grants, (*2*) support of agricultural experiment stations, and (*3*) direct research.

With the passage of Public Law 159 of the 84th Congress in 1955, provision was made for the granting of funds to individual research workers in the field of air pollution for specific projects. During the almost five years intervening, some three and one-half to four million dollars have been awarded under these grants. It is difficult to assess the amount of work being done under these funds that is of interest to agriculture. Some of the grants, such as one

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† Chemist, Soil and Water Conservation Research Division, Agricultural Research Service, United States Department of Agriculture on co-operative assignment to the Public Health Service, United States Department of Health, Education, and Welfare.

on the Effects of Fluorides on Basic Plant Processes, are of primary interest to agriculture. Others, such as one for study of Aeroallergens by Hewson and Sheldon of the University of Michigan, are mainly concerned with medical aspects. However, since considerable work is being done under the latter project on the problem of hybridization of ragweed and the distribution of its pollen, the Michigan study is of considerable interest to agriculture. I will not attempt to cite all of the projects that have an agricultural interest, but only to cover briefly those which I feel are pertinent to demonstrate the type of work being supported.

In addition to the project mentioned above on the Effects of Fluorides on Basic Plant Processes, conducted by McNulty at the University of Utah, there is a study underway by Adams at Washington State College on the Biochemical Response of Plant Tissue to Hydrogen Fluoride Fumigation. These studies are adding to our knowledge of what happens to fluorides in the plant and what essential processes are affected. The two projects are closely allied to the agricultural experiment station projects to be mentioned later and represent part of a loosely integrated attack with both public and private funds upon the general problem of fluorides as air pollutants affecting agriculture. There is also a project on the possible effects of atmospheric fluorides on man.

Some of the work of Mrs. Glater in Los Angeles in her early investigations of the site and mode of injury induced by smog was supported by these grant funds. There is currently a grant to Dr. Stewart of the Los Angeles County Arboretum on the Effects of Air Pollutions upon Tissue Growth of Plants, and a grant to Freebairn of the University of California, Riverside, on the Biochemical Effect of Gaseous Oxidizing Agents on Plant and Animal Metabolism. Both of these projects are aimed at better detailing the physiological and biochemical effects of the smog type of air pollutant. Stewart's group is using tissue culture techniques, and Freebairn will use homogenate and cell fragment techniques. There are several other projects primarily in the medical field directed towards the determination of the effects of the smog type air pollution upon the physiological responses of animals and man. As these results become available, they will be of importance in the veterinary aspects of agriculture, as well as adding to our knowledge regarding effects on basic life processes. There are other projects designed to delineate the chemical reactions occurring in the air. These studies will have a direct bearing upon describing the atmosphere to which plants and animals are subjected, and hence upon the agriculture of the affected area. Hall at Agricultural and Mechanical College of Texas has recently initiated a grant-supported study on the effects of hydrocarbon air pollutants with particular reference to the unsaturated series.

Various agricultural experiment stations have worked on problems of air pollution; for example, studies by the Oregon and Washington Experiment Stations on the fluoride problem in the Sauvie Island Region in the Columbia River Valley,[1] as well as other earlier aspects of the fluoride problem in the Pacific northwest.[10] In making any attempt to assess the total contribution of Federal funds to the exploration of the air pollution problem, such studies as these must be considered as having been partially and indirectly supported by the federal government. The very existence of these experiment stations, the staff, the facilities, and the competence that they had in initiating these investigations were dependent upon the expenditure of certain federal monies. However, this is incidental credit by association which should not be carried too far.

Within the agricultural experiment stations of the western states there has been direct federal support for research work on fluorides as they affect agriculture. A certain amount of the monies appropriated to the Division of Experiment Stations within the Department of Agriculture is for support of regional projects. It is from these funds that the Western Regional Project W-39 on the Effects of Fluorine on Plants, Animals, and Soils is supported; the total of $25,000 a year supporting projects in California, Idaho, Utah, and Washington. In all of these states there are other fluoride projects supported by other experiment station funds.

In recent years, the majority of direct air pollution research conducted by various agencies of the federal government has been supported under Public Law 159. Within the area of agricultural interest, the amount of federal support in relation to the support by nonfederal agencies has probably been less than in any other area of interest.

The office which I represent is the major direct federal effort on air pollution related to agriculture. This is a co-operative arrangement between the Air Pollution Engineering Research, Public Health Service, and the Soil and Water Conservation Research Division, Agricultural Research Service. Established in 1956 and located at the Sanitary Engineering Center in Cincinnati, the unit has a threefold purpose: first, to maintain liaison between the two departments on air pollution matters; second, to give some technical competence in the field of agriculture to the engineering research program; and third, to initiate a research program in the field of plants as measures of air pollution. At the present time this research aspect of the program is concerned chiefly with the auto exhaust studies of the air pollution engineering group. This unique facility for irradiating diluted auto exhaust under controlled conditions[13] will permit studies which should give some of the desired basic information on the response of plants to this component of urban air pollution. This group also has been investigating the possible use of a bioassay evaluation of the particulate material collected in the National Air Sampling Network.

There has also been direct support by federal funds other than Public Law 159. Since I cited the early work of two of the experiment stations in the fluoride problem, I should also cite some direct work by the Department of Agriculture in this field on the early fumigation of plants with fluoride at its Beltsville Station. This was reported at the First National Air Pollution Conference.[8]

More recently the Crops Division of the Agricultural Research Service has supported research in air pollution in the studies of the disease, tobacco fleck. This is an excellent example of a spontaneous co-operative effort of a diverse group. The possibility that fleck could be an air pollution problem had been raised in discussions with workers at the Tobacco Substation of the Connecticut Agricultural Experiment Station in 1956, but at the time no clear evidence was available. When the possible cause of stipple disease on grape was reported as ozone,[12] workers in the Crops Research Division of the Agricultural Research Service noted the similarity to tobacco fleck. As a result of an exchange of information and co-operative studies among workers of the Connecticut Substation, the California Agricultural Experiment Station at Riverside, the United States Weather Bureau, the Public Health Service, and the Crops Division, it has been established that tobacco fleck disease results from elevated ozone levels.[6, 14]

Future Efforts

That agriculture is significantly affected by air pollution is well recognized. That the problem will continue and grow is as inevitable as our continued industrialization and urbanization. That agriculture must accept responsibility as a producer of air pollution is also well recognized. Spray programs, waste disposal, cultivation practices,

handling and processing of agricultural products, all give rise to many air pollution problems of dusts, aerosols, and odors. These are often only in the realm of nuisance, and that difficultly assessable area of soiling and personal discomfort, but also often with the potentiality of serious injury to health and well-being.

The work outlined above, supported by federal funds, is only a fraction of the total in the field of the effects of air pollution on agriculture. Since much of the work has been supported by industries and local public funds, it has been directed towards local problems: identification, definition of the problem, description of the symptomatology and, within the limits of this gross symptomatology, measurements of response. This work must continue.

The purpose of investigations and research in this field is to yield the observations and hypotheses by which the problem may be delineated and limited, and upon which the limits of a solution may be based. No amount of research or investigation will in itself ever solve an air pollution problem. The agricultural committee, meeting within the Air Pollution Research Planning Seminar in December 1956[9] attempted to define in broad terms the research needs in this area of air pollution in relation to agriculture. The committee recognized the need for more studies on symptomatology, more delineation of the distribution of known toxicants, more assessments of economic loss, more information and assistance from analytical chemists, engineers, and meteorologists; but also they emphasized the environmental aspects of air pollution. It was pointed out that the ultimate effect of air-borne toxicants upon biological materials is determined not alone by the concentration of the toxicant or by the time of its reaction, but rather by the interaction with the other environmental factors to which the organism is exposed.

There are two areas of investigation from these considerations, although the line of demarcation between the two is not always distinct. In the first we approach the problem from the field under the conditions of environment in the area of interest. In the second we approach the problem from the laboratory under controlled conditions with little relation to the local environment, but examining the interaction with the controlled environmental factors. Field and laboratory may not have the proper connotation to describe the two approaches. Perhaps local and general would be better but these two terms also leave much to be desired. They do not indicate the interdependence of the two approaches, and some will associate a higher degree of importance to one than the other. It is important, however, that we make the distinction between the two approaches, since this presents a basis for support of investigations in air pollution as they affect agriculture, from federal as well as other public and private funds.

Certainly in seeking the needed foundations upon which to base a sound, economically feasible solution to a specific local problem, we must obtain certain local information from the field and sometimes from other plants grown under conditions approaching the environment found in the locality. The support and direction of these local studies is primarily the responsibility of the local agencies concerned. The Federal Government has a responsibility for lending technical assistance and sometimes supplementary support to these studies as needed. However, the conduct of these investigations and the conclusions drawn from them will be sounder if we have a thorough understanding of the physiological responses of organisms to the toxicant of interest. It is only from a knowledge of the effect of toxicants on essential biological processes that we can design the best field approaches to study of an air pollution problem, and best interpret the data gained. The information gained in field studies of the effects of fluorides on pine trees in Washington will not necessarily be of value in a study of the effects of fluorides on citrus in Florida. On the other hand any information gained from the pine tree study upon the effect of fluorides on basic plant processes will be applicable to the citrus problem. Yet this information will not be sufficient to form the foundations of a solution to the citrus problem without the supporting evidence from well-planned field work in the locality of interest.

These important investigations, necessary as a foundation for the ultimate solution of many of our existing air pollution difficulties, are being done in bits and pieces. This, by the very nature of the work and its dependence upon the imagination and ingenuity of the investigator, is necessary. This type of work can seldom be directed, but must always be encouraged. Nevertheless, the individual worker, although encouraged by local interest in an air pollution problem, is at the same time pressured for immediate answers. Local support, unfortunately, often fades before the investigator can carry his studies to a definitive conclusion. Leadership is needed, as well as supplementary support of these studies of the physiological response of plants and animals to known and suspected toxicants in the air. The federal government must supply this leadership and such supplementary support as is required. However, industry and local agencies, public and private, have a responsibility to continue work in this field and must be encouraged to do so.

The role, then, of the federal government in the field of air pollution as it affects agriculture is necessarily twofold. It should provide technical assistance and supplementary funds to states, communities, and other agencies in approaching the solutions to air pollution or in collecting the data upon which solutions can be based. More importantly, it should provide the leadership in the necessary general investigations of the effects of known or suspected air-borne toxicants upon fundamental processes of plants and animals. The needs for technical assistance from the standpoint of air pollution effects upon agriculture as well as agriculture's contribution to air pollution, can probably best be directed through Public Health Service implementation of Public Law 159 and its extension, Public Law 365 of the 86th Congress. Some of the general work needed can be supported through the grants program under the Public Health Service. I believe, however, that the Department of Agriculture must provide the leadership in obtaining the basic information needed.

The Department of Agriculture, by its organization and prior experience, is well equipped to give this leadership. While not divorcing itself from the local problem and its needs, it can detach itself sufficiently to point the way through the areas of investigation that are necessary to the solution of a group of problems, and in this way stimulate other work and give it a certain amount of direction. It has been recommended that the Department establish a small research group in this field of response investigations organized along lines similar to the United States Plant, Soil, and Nutrition Laboratory or as a Pioneering Research Group. One essential element of these recommendations is the maintenance of a technical service and liaison activity with the Public Health Service Air Pollution Group. It has also been suggested that provisions be included for stimulating and assisting local research groups in their basic investigation efforts with grants and contract funds. The proposal has been favorably received, yet at the present time the funds available have not permitted implementing such a program.

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(*Continued on p 257*)

A SIMPLIFIED METHOD *for* CHARACTERIZING *a Motor Vehicle's* EXHAUST EMISSIONS*

A. M. SMITH and **J. H. STRUCK,** Engineering and Research Staff, Ford Motor Company

In the last decade, interest in automobile exhaust gas measurement has markedly increased because of the suspected relationship between certain exhaust components and photochemical-hydrocarbon type air pollution, or smog. Because of the rapidly varying composition and volumetric flow of exhaust gas during typical road operation, there has been extensive research to develop methods for evaluating the exhaust emissions of an individual vehicle.

Infrared techniques[1] have been applied for continuous measurements of "total" hydrocarbons, carbon monoxide, and carbon dioxide. To relate these concentrations to total emissions, methods have been developed for measuring carburetor air flow[2] and computationally making an approximate integration of the product of exhaust flow and component concentration to determine weight of component emitted during a traffic cycle. Steady state concentration measurements should be used for these calculations because of sample system hang up and the variable time delay between carburetor flow and exhaust system flow.

The Co-ordinating Research Council has conducted field surveys[3] to measure the vehicle exhaust emissions of customer cars. In so doing a tremendous complexity of instrumentation and data analysis has resulted in an extremely large material and man-hour cost to determine exhaust emission rates to the atmosphere. Continuing research is being carried out to facilitate future surveys and inspection station operations. An early approach[4] was the electronic integration of the flow-concentration product during a traffic cycle operation. This method failed to achieve wide acceptance because no compensation for sample system hang up could be made as was done using the computational system.

In recent years, one laboratory has been working on the development of a proportionate sampler[5] for simplifying exhaust measurements by the continuous sampling and storage of the exhaust stream in proportion to the carburetor air flow. This system apparently works well over extended traffic route operation. Other laboratories have recognized the basic utility of this approach, and are working on the development of proportional sampling systems. It is recognized, however, that this tool is not well suited to survey operations.

A simple absolute solution to much of the complexity, cost, and lack of confidence in the measurement of total exhaust gas emissions has periodically been proposed and passed over: collect and make measurements of the composition and volume of all of the exhaust gas emitted by a vehicle. Reflective consideration revealed that an automobile operated over a minimal traffic cycle would exhaust less than 200 cubic feet of gas and that plastic bags capable of containing this volume could be readily obtained. This paper describes the investigation of the technical and operational feasibility of collecting total exhaust gas during a four minute traffic cycle and measuring the component concentrations in order to characterize, rapidly and accurately, the emissions of a vehicle.

Discussion

Investigations carried out by a number of laboratories indicated that Mylar

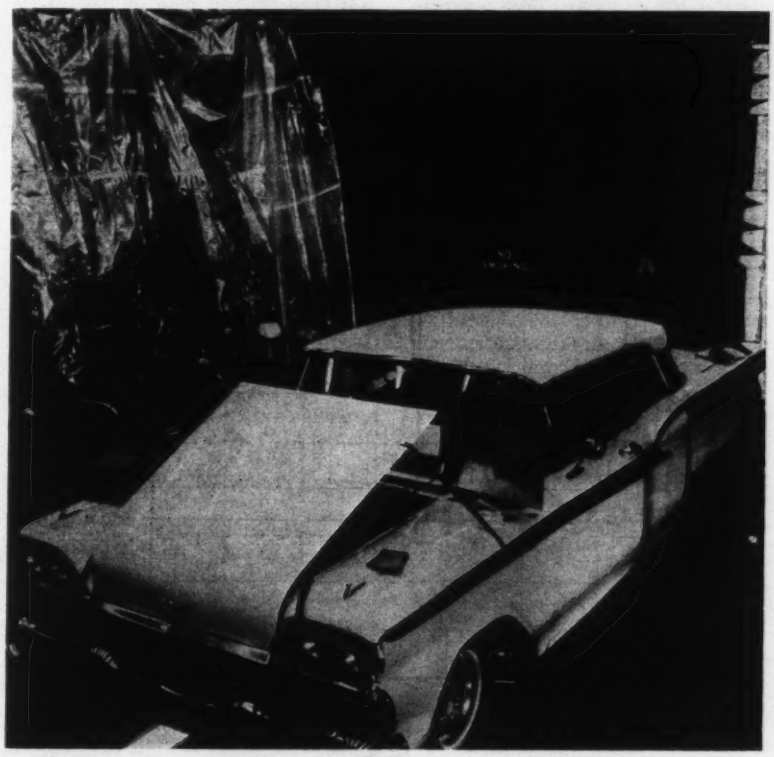

Fig. 1.

* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

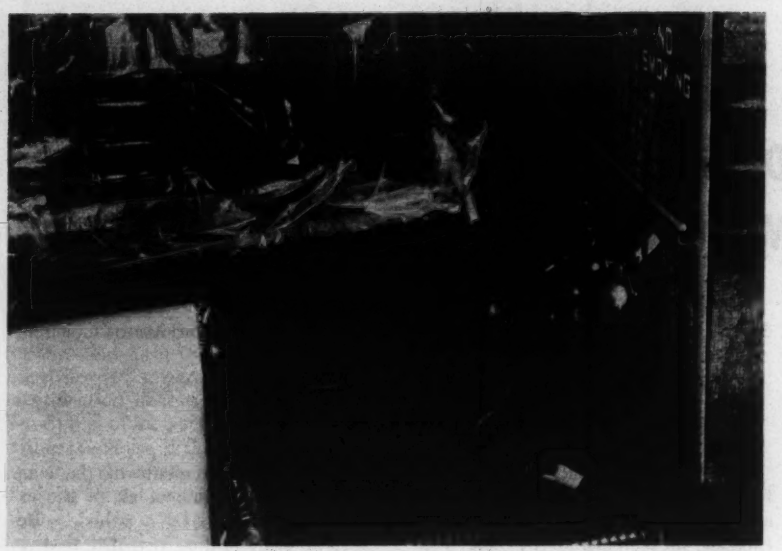

Fig 2.

plastic is chemically stable and does not absorb hydrocarbons. It was thus felt that a plastic bag made by Mylar film could be evacuated and attached to the tailpipe of an automobile to capture the total exhaust from the vehicle as it was operated through various driving conditions.

For the first tests of this concept, bags were made of two sheets of Mylar film, 14 feet square, and sealed on all four edges. All tests were conducted utilizing a vehicle installed on a chassis dynamometer (Fig. 1). This dynamometer has an inertial mass approximately equivalent to a 6000 lb vehicle and a steady cruise loading normal for a 3500 lb vehicle.

In the background of Fig 1 can be seen a plastic bag suspended from the ceiling of the chassis dynamometer laboratory. Figure 2 shows the tailpipe extension as it enters the plastic bag. Not shown is the heat exchanger used to cool the exhaust stream before it enters the bag.

The first objective of the investigation was to determine if the bag could collect all the exhaust from the tailpipe and retain it unchanged for future measurement. To do this the test vehicle was driven at a steady 30 mph until stability had been reached both in the vehicle and in the sampling system as indicated by stable exhaust gas temperature and by stable exhaust hydrocarbon, carbon monoxide, and carbon dioxide concentrations. Engine manifold depression and rpm were also checked, and the exhaust system was inspected to make sure that there was no leakage. Instruments used for continuously monitoring the exhaust stream were Liston-Becker nondispersive infrared analyzers for measuring hydrocarbons, carbon monoxide, and carbon dioxide. The hydrocarbon analyzer was equipped with a hexane detector and a five-inch sample cell.

After stabilization was achieved, the exhaust stream was diverted into the evacuated plastic bag. After four to five minutes of vehicle operation at 30 mph road load, the bag was disconnected from the exhaust stream and sealed except for a gas sampling probe. Using the same hydrocarbon, carbon monoxide, and carbon dioxide instruments which had been monitoring the exhaust stream it was found that the concentrations in the collected exhaust were indistinguishable from those measured in the test vehicle exhaust pipe.

Having established that the plastic bag collected all the exhaust and momentarily retained it unchanged, it then became desirable to determine how long the bag sample would remain unchanged as determined by the instrumentation mentioned above. At the end of one hour of exhaust gas storage within the plastic bag there was no detectable decrease in hydrocarbon, carbon monoxide, or carbon dioxide concentrations using Mylar material for the bag.

The Mylar bags were used repeatedly, being flushed with air after each use to remove all traces of the previous exhaust gas. This process, however, proved awkward and time consuming. It was felt that bags made of a less expensive material could be thrown away after one use at less over-all cost than attempting to re-use the more expensive Mylar bags.

One of the least expensive and most readily available sheet materials for this application is polyethylene. Since polyethylene is a well-known absorber of hydrocarbons it became important to determine if this absorption of hydrocarbons would make polyethylene unacceptable for this application.

A second step in the program was thus initiated to check the feasibility of using polyethylene as a bag material to determine the time stability of these kinds of exhaust gases when stored in the bags. There was no measurable decrease of carbon monoxide or hydrocarbon concentrations during the first hour's storage and only a few percent after four hours' storage.

It can be concluded from all experience with the polyethylene bags that no appreciable concentration change in the bag is detectable with the

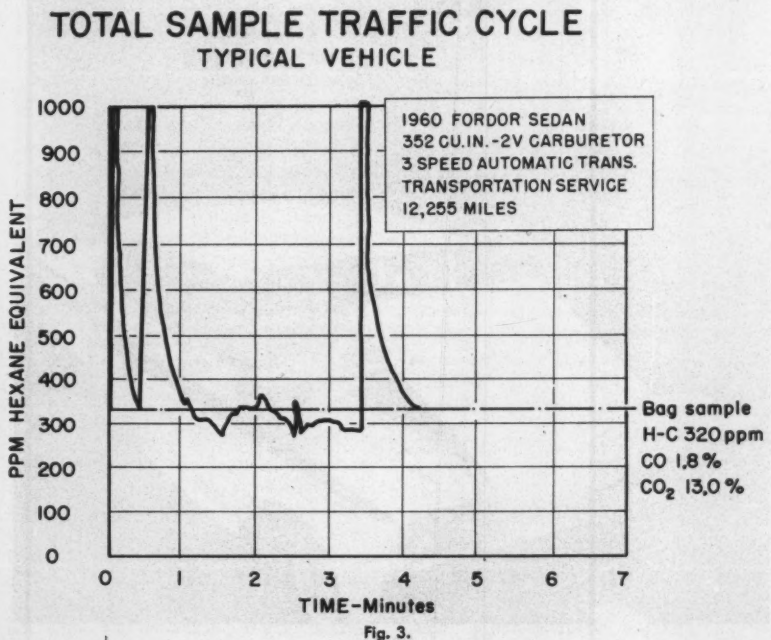

Fig. 3.

Table I—1960 Car Exhaust Emission Characterizations

Car No.	Mileage	Engine Displacement In.³	Automatic Transmission Type	Rear Axle Ratio	Steady State C-50 HC Ppm Hex	Steady State C-50 CO Mol %	Steady State C-50 CO_2 Mol %	Idle During Traffic Cycle HC Ppm Hex	Traffic Cycle Total Sample HC Ppm Hex	Traffic Cycle Total Sample CO Mol %	Traffic Cycle Total Sample CO_2 Mol %
6T92	3528	352	3 speed	2.91:1	280	1.3	13.6	500	420	1.3	12.0
6T101	3896	352	3 speed	2.91:1	190	0.9	13.7	250	260	1.4	13.7
6T94	12255	352	3 speed	2.91:1	190	0.9	13.8	310	320	1.8	13.0
6T124	2809	292	2 speed	3.10:1	180	0.6	13.2	340	280	1.9	12.5
6T104	3384	352	3 speed	2.91:1	200	0.7	13.9	330	290	2.0	12.7
6P149	1594	292	2 speed	3.10:1	180	0.7	13.0	290	280	1.9	12.6
6P146	1506	292	2 speed	3.10:1	190	0.4	13.2	500	300	2.0	12.4
6P148	839	292	2 speed	3.10:1	200	0.8	12.9	700	390	1.9	11.7
6P168	2162	292	2 speed	3.10:1	220	0.5	12.8	530	360	1.5	11.6
6P155	1538	292	2 speed	3.10:1	180	0.4	12.3	300	300	1.5	11.8
6P158	1209	292	2 speed	3.10:1	210	0.5	12.6	420	380	1.8	11.9
6P169	1139	292	2 speed	3.10:1	180	0.4	12.7	480	360	1.8	11.6
6P159	1432	292	2 speed	3.10:1	190	0.5	12.7	490	320	2.1	11.4
6P150	1266	292	2 speed	3.56:1	220	1.1	12.5	550	400	1.7	11.7
				Avg	201	0.7	13.1	428	333	1.76	12.2
				Std dev	26	0.27	0.49	124	49	0.24	0.6

instrumentation used within the first few minutes after filling. It appears that inexpensive polyethylene bags can be used to collect total vehicle exhaust and retain it for accurate measurement. More chemically stable bags will probably be required for flame detectors and other broader range hydrocarbon instrumentation.

At this point in the investigation it had been established that this technique could be used under steady state driving conditions to collect the total flow of exhaust gas and that the characteristics of the collected gas would be identical to those of the exhaust stream. However, to characterize typical exhaust emissions from an automobile, it was felt necessary that the vehicle be operated in a manner more representative of actual customer driving. The next step in the program was to collect in a plastic bag the total exhaust gas from a vehicle which was being operated through a representative driving cycle. The driving cycle selected was adapted from the one used by the Co-ordinating Research Council in the 1956 Field Survey. This Total Sample Traffic Cycle is given in the Appendix and requires four minutes to complete.

A test vehicle was installed on the chassis dynamometer and operated at 50 mph cruise for five minutes to provide uniform vehicle conditioning. Utilizing the instrumentation previously described for continuous recording of hydrocarbon, carbon monoxide, and carbon dioxide concentrations, an evacuated plastic bag was used to collect the total exhaust from the vehicle as it was operated through the traffic cycle. Figure 3 shows the exhaust stream hydrocarbon trace vs time as recorded during the operating of the test vehicle through the traffic cycle. At the conclusion of the test the same hydrocarbon analyzer was used to measure the hydrocarbon concentration in the bag. The volume of the exhaust gas captured in the bag during the driving cycle was determined by use of a wet test meter. For this particular vehicle a measurement of 140 standard cubic feet was obtained.

Having proved the accuracy and utility of this technique for characterizing total vehicle exhaust emissions, it was decided to prove operation feasibility by measuring the emissions of a large sample of vehicles. Previous efforts to characterize tailpipe emissions have involved measurement of carburetor air flow (to provide exhaust flow data) and exhaust concentrations during particular driving conditions (idle, acceleration, cruise, and deceleration) plus extensive and tedious data analyses to synthesize "average concentrations." As the last step of the program, 14 vehicles were driven through the Total Sample Traffic Cycle on the chassis dynamometer and 14 plastic bags were filled and the concentrations measured by four men in four hours. The data obtained during these tests are shown in Table I.

Because of inherent accuracy, utility, and simplicity, it is felt that the technique described in this paper should find ready acceptance for such applications as:

1 Field surveys of vehicle populations.
2 Inspection station measurement of vehicle exhaust emissions.
3 Evaluation of exhaust system control devices.
4 Calibration of proportionate sampling systems.
5 Measurement of exhaust gas flow rates.
6 Engineering studies of the effects of engine, fuel, lubricant, and/or other variables on total exhaust emissions.

It is also felt that this technique would lend itself to road operation through utilization of a plastic bag properly sized to fill the interior of the vehicle behind the driver.

Summary

An absolute technique has been developed for characterizing the exhaust emissions of an automobile as operated through a complete traffic cycle. The technique involves the collection of all of the exhaust gases in an evacuated plastic bag. Subsequent measurements of the composition and volume of this total sample can be accomplished using any available laboratory measuring technique.

Plastic bags of Mylar film were shown to result in no change in hydrocarbon, carbon monoxide, or carbon dioxide concentrations for one hour after bag filling. Plastic bags made of polyethylene are considered usable if measurements are made immediately after filling the bag.

The inherent accuracy, utility, and simplicity of this technique will eliminate many of the current measurement problems now plaguing those involved in evaluating automobile exhaust emissions.

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(*Continued on p 258*)

Unsolved PROBLEMS *with* FLUE-FED INCINERATORS*

ELMER R. KAISER, Senior Research Scientist, College of Engineering, New York University, New York, N. Y.

Importance of Flue-Fed Incinerators

The Proceedings of the 52nd Annual Meeting of the Air Pollution Control Association included two reports[1, 2] on recent improvements to flue-fed incinerators and two summaries[3, 4] of general experience and viewpoints regarding air pollution from older designs. Although the use of the combustion devices, hopper locks, and gas cleaning devices advocated in the first two reports will go far toward meeting the objections against the flue-fed incinerator that were voiced in the second two papers, it is obvious that additional facts and improvements are needed. A variety of incinerator features that have not been evaluated sufficiently are advocated in some localities but have not been adopted in others. In other cases, problems remain for which satisfactory solutions are still to be discovered. The outlook for further progress is optimistic.

The flue-fed incinerator fills a definite need in modern apartment buildings, but it is a recognized source of air pollution in residential areas. It is the purpose of this paper to stimulate consideration of some of the factors in need of investigation in the hope that progress will continue. In some cases solutions to problems will be suggested, but tests will be necessary to determine their value.

Incinerators in the basements of multi-story apartment buildings greatly simplify the disposal of refuse by reducing the weight and volume to 35 and 10%, respectively.[2] This reduction in the amount of material to be transferred by containers and hauled through city streets is an obvious benefit. The operation of the incinerator is so simple that one operator can tend 10 incinerators in a group of as many buildings which house 3000 persons. As the incinerator chimney or flue also serves as the refuse chute, and the tenants can deposit the refuse in charging hoppers on the flue in the hallway near the apartment, and at almost any convenient time, the transfer of refuse to the incinerator by gravity is simplicity itself. Even the disposal of oversized combustible refuse, such as cartons and discarded furniture, does not require removal from the building where such incinerators are in use.

Because alternate methods of refuse disposal entail more labor, nuisance, and expense, further consideration should be given to developing apartment-house incinerators, particularly to reduce their emissions of fly ash, combustible particles, and noxious gases. Auxiliary gas burners and overfire air jets improve combustion but the control of fly ash is an independent matter.

Configuration of Combustion Chamber

The typical single-chamber incinerator furnace receives refuse from a flue that extends above one rear corner of the furnace roof, as shown in Fig. 1A. The refuse accumulates under the flue in a sloping pile which has an angle of repose of close to 45 degrees. The furnace volume is poorly utilized, especially when the furnace is relatively large and not high. As the result, the top of the pile soon reaches the flue and often extends well up into the flue, thereby blocking the passage of gases. In the latter case, when the attendant does not rake the refuse away from the flue entrance, he ignites the top of the refuse by dropping a lighted taper through a lower-floor refuse hopper. When an opening has burned through the refuse in the flue throat, the gas velocities increase rapidly and cause paper and much dust to be entrained and carried up the flue.

For new installations consideration might well be given to a central location of the flue in the furnace roof, as suggested in Fig. 1B. As the refuse can roll away in all directions from the apex of the pile in this design, the furnace space is more fully utilized, and the clearance between the apex and the flue is increased. The gases can enter the flue from four sides and will flow at lower velocities. Overfire air manifolds can be applied as shown to provide

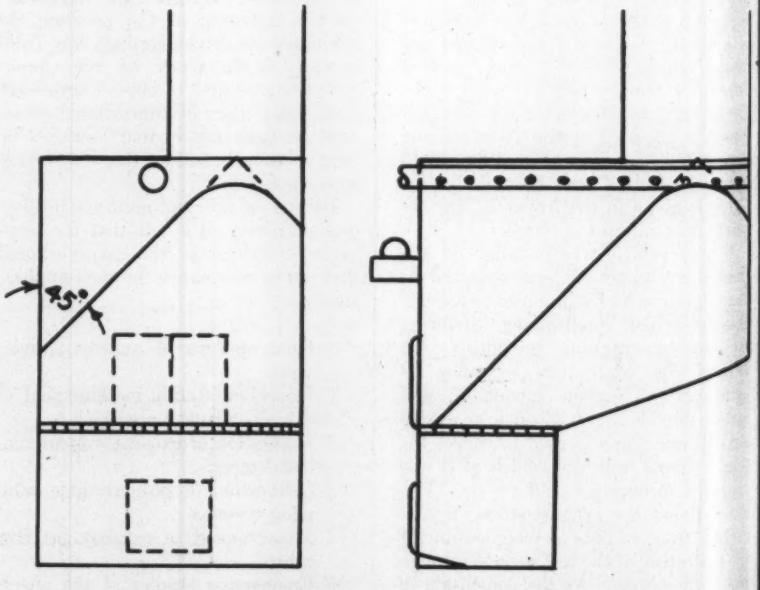

Fig. 1A. Typical single-flue refuse incinerator with corner flue.

* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

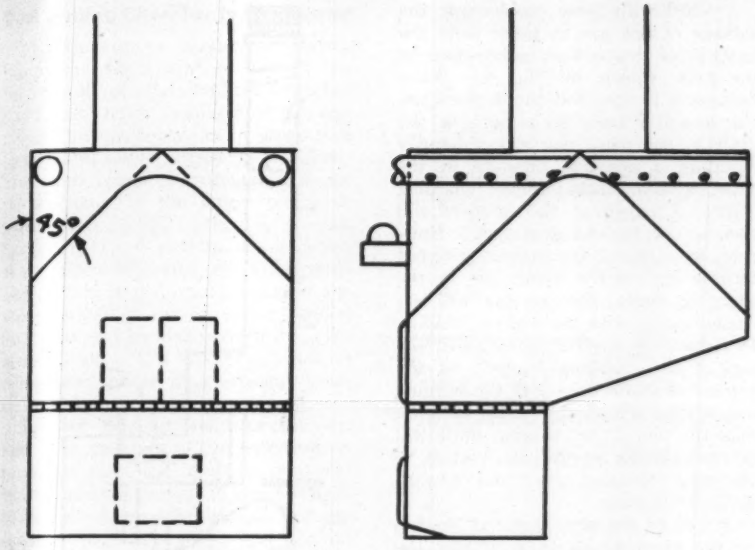

Fig. 1B. Typical single-flue refuse incinerator with central flue.

combustion air to all surfaces of the pile. The construction of a furnace roof with central flue presents no unusual difficulty.

A higher furnace with flat roof and corner flue is only a partial substitute. However, to centralize the flue in the furnace roof, it is necessary for the architect to modify slightly the usual arrangement of one interior basement partition, as the incinerator location must be displaced accordingly.

In the sizing of the furnace, it is advisable to assume that one lb or 0.25 cu ft of refuse per occupant will be dropped into the furnace between late afternoon and early the following morning.[2] Based on actual measurements in the incinerator, the bulk density of present day domestic refuse is only four lb per cu ft because of the high proportion of paper. The top of the charge should not be allowed to extend beyond one foot of the flue entrance. One should not assume that the furnace can be made smaller in the expectation that the attendant will rake the refuse away from the flue. The available refuse space can thus be calculated by assuming a pyramidal pile whose theoretical apex is at the center of the flue opening, whose sides slope at 45 degrees, and whose sides are bounded by the walls, grate, and hearth.

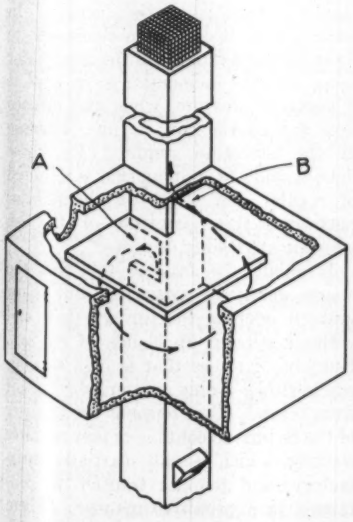

Fig. 3. Roof settling chamber for flue-fed incinerator.

Leakage of Flue Gas into Buildings

In its simpler cases the incinerator flue provides ample draft for combustion of refuse and sufficient draft differential between the occupied areas and hallways of the building so that flue gas does not leak out at the hoppers. Unfortunately, a number of practices and factors are at work in some buildings that cause minor to occasionally severe gassing out at the hoppers. Black smudges on the walls above the hoppers, burnt odors, and discomfort while charging refuse are among the manifestations of the problem. Several causes may be cited:

1 The plugging of the spark arrester screen by paper carried up by the flue gases during the period of rapid burning is not an uncommon difficulty where refuse is charged during burning or where the incinerator attendant has not controlled the ingress of air to the furnace. When the escape of flue gas is thus largely blocked, a positive pressure of flue gas is instantly produced in the upper part of the flue, causing odorous and smoky flue gas to issue around the hopper doors. To restore the draft by unplugging the screen, which is high above the roof, hinged doors have been provided on some spark arresters. When opened, the paper blows out over the neighborhood.

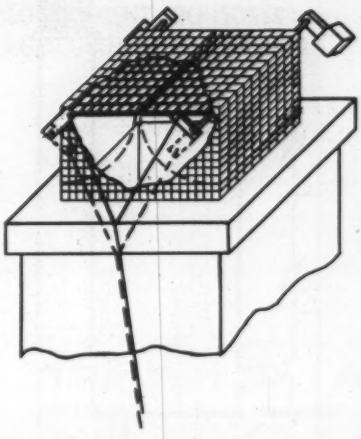

Fig. 2. Secondary screens in spark arrester.

Figure 2 illustrates hinged screens inside the conventional spark arrester which could be pivoted promptly to unplug two areas without discharging the collected paper. After the incinerator has burned down, the relief screens can be raised and the paper allowed to fall back into the incinerator. Trial installations have not been made to test the suggestion. Another solution now being tried in New York is a taller screen to provide double the area, hence reducing the likelihood of plugging.

The use of electric hopper locks to prevent the charging of refuse during burning would prevent the difficulty in most cases, but the suggested screens would insure prompt relief in unusual circumstances.

2 Roof settling chambers are another resistance to the flow of flue gas and they frequently cause gassing out of the upper-floor hoppers. Figure 3 illustrates one form of dust settling chamber on the roof, the object of which is to trap dust and paper with minimum loss of draft. The gases enter the chamber through a side opening in the chimney, and re-enter the same chimney above the flue block. A horizontal baffle between the openings prevents shortcircuiting of the gases.

Unfortunately, the draft losses are quite significant. The gases make two right-angle turns in square elbows, lose their initial velocity head, turn 180 degrees around the horizontal baffle, and must regain the velocity head on re-entering the flue. If openings A and B have less than the cross-sectional area of the flue, the draft loss is even greater. The theoretical draft loss is thus close to five velocity heads, based on the velocity

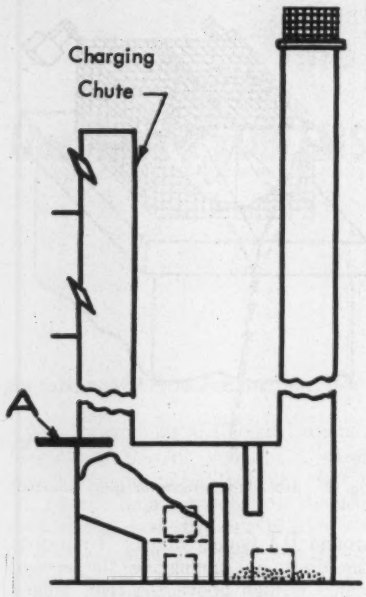

Fig. 4. Double-flue incinerator.

in the chimney, or about 0.02 in. wc at five fps.

As the chimney above the roof chamber is ordinarily short, and has not warmed appreciably by the time of the maximum gas velocity, its stack effect is insufficient to overcome the total draft loss of the settling chamber. Flow is sustained by virtue of a positive pressure in the flue below the settling chamber. The positive pressure from the buoyancy of the gases in the flue passing through the upper floors causes gas leakage from the upper-floor hoppers. The effect is mitigated in some cases by draft effects induced by wind over the buildings and by positive pressures in the upper floors of some buildings during cold weather. However, in general, a motorized draft booster would be required on the stack above the settling chamber.

The roof settling chamber is not regarded favorably by many because of its remote location, high initial cost, and the ease with which periodic cleaning has been overlooked in the past. Its efficiency is generally satisfactory in collecting large particles and in keeping the arrester screen open, but better devices have been developed. Explosions have occurred in such chamber, with resultant destruction.

3 Exhaust fans in apartment buildings, and particularly in highly ventilated hospitals, reduce the static pressures sufficiently in some cases to cause leakage of flue gas and odors from the flues into the occupied areas. To provide the necessary ventilation without upsetting the balance of draft, it is necessary to blow air into the occupied spaces to equal the air exhausted. This principle is frequently overlooked.

4 Allied with these problems is the leakage of flue gas at times from the hoppers of double-flue incinerators of the type shown in Fig. 4. When damper A is open but the hoppers are closed, and a lively fire is burning, the draft in the main flue will ordinarily maintain a negative pressure in the entire system, including the charging chute. Leakage at the hoppers will then be into the charging chute. However, by virtue of the buoyancy of hot furnace gas in the colder air in the charging chute, furnace gas will exchange places with the cold air, tending to reduce the negative pressure at the top of the charging chute. As the furnace draft declines with the burning out of the refuse, the static pressure near the top of the charging chute will become slightly positive in relation to the upper occupied space, and outward leakage will occur.

A vent to the atmosphere at the top of the charging chute is hardly the answer, because it would only promote the flow of additional furnace through the charging chute before such gas had been thoroughly burned in the furnace.

The closing of damper A during burning necessitates the use of hopper locks as well, because refuse dropped on the damper would soon cause it to bind or be damaged. Such dampers are only relatively tight, which fortunately would permit ingress of chute air to the furnace without the furnace gas displacing it in the chute.

Incinerator with By-Pass Flue

By employing a by-pass flue, the multiple-chamber incinerator can be used with a single flue, as shown in Fig. 5. Combustion can be completed to a high degree by the use of overfire air jets and auxiliary gas firing. Damper A is required, as well as hopper locks. The settling chamber B traps some of the fly ash and paper. Barometric damper C is helpful in limiting the stack draft and burning rate, but adds large volumes of air to the flue, which promote the entrainment of dust in the flue, and add to the volume of gas to be cleaned by a scrubber at or near roof level. An alternative method to be developed is the control of air ingress to the furnace which is as reliable as the barometric damper, but which is nearly independent of stack draft.

As in the case of the single-flue incinerator, the by-pass flue incinerator needs improvement in the firing practice. After the exposed dry paper has burned off the charge, and the total volume has been reduced to about 25% of the original, the remaining charge consists of a compacted and nearly impervious mass of damp paper and food remains, under a covering of tin cans, bottles, ash, and charred paper. The flames have nearly subsided and

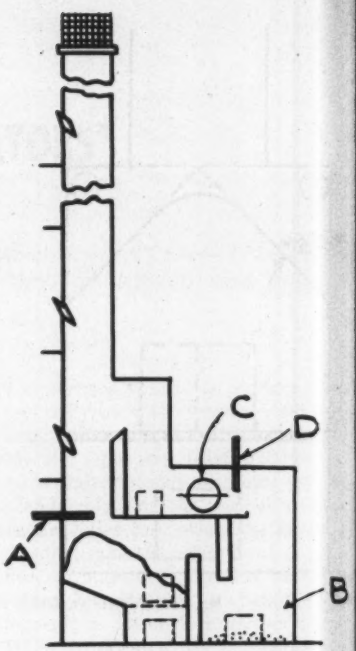

Fig. 5. Incinerator with by-pass flue.

the furnace has partly cooled by ventilation. The damp charge is burning too slowly, despite the effect of auxiliary gas heat and overfire jets.

To expedite incineration it is necessary to pull or wing the remaining charge from the hearth to the grate and thus to invert the material and expose the matted refuse to combustion air. Combustion resumes vigorously during raking, often with excessive entrainment of fly ash by the furnace gases, unless a sliding damper D is partly closed or the barometric damper is blocked open.

The simple, single-flue incinerator is worst in this respect because the full chimney draft is on the furnace. In some places it has been necessary to limit the ingress of air to the incinerator room, and the incinerator room kept at a negative pressure, while the furnace door was open to work the fire. Because of the attention required for these details, and the training that is required of regular and substitute incinerator operators, these controls of fly ash emission are readily neglected.

It should be feasible to open the charge gently by agitation from below without opening the furnace door and without stirring up clouds of fly ash. Burnout of refuse that is high in noncombustibles is only accomplished by air from below. After burnout the transfer of the residue to containers now requires wetting, which is only partially satisfactory, and manual transfer to containers in a primitive manner. There are opportunities for invention in this area.

Dust Settling Chamber in Incinerator

The amount of particulate matter trapped in the chambers beyond the bridge-wall of the multiple-chamber apartment refuse incinerator is significant but probably low in proportion to the total solids carried by the gases. The main benefit is recognized to be the trapping of the larger pieces of paper that would otherwise wreak havoc in the spark arrester. A succession of chambers separated by bridge-walls and curtain walls would increase the solids caught at the expense of added draft loss and capital investment. An investigation of this type of collector on refuse incinerators in apartment-house service is long overdue.

A more efficient collector directly after the paper trap has often been considered, but the high gas temperatures would rule out some types of dust collectors. A gas scrubber has features suitable for this service because the metal is protected by water sprays. The automatic flushing of solids to the sewer is an added benefit. The scrubber exhaust fan would also provide the draft to operate the incinerator and to control the flow of air to the furnace at a nearly uniform rate. The latter advantage would practically eliminate the problems caused by chimney draft, as discussed earlier.

A commercial scrubber with impingement plates showed over 90% collection efficiency on flue dust from apartment refuse when operated on gases up to 250°F near the building roof.[2] The scrubber also reduced the emission of organic vapors. The flue gases were half infiltration air which had entered the flue through numerous hopper vents. Far less gas would have to be cleaned if taken directly from the incinerator.

The exhausting of the gas from the scrubber would be a problem in a basement installation because the gases would be moisture saturated and at a temperature somewhat above that of the incinerator flue. The gases would cool and condense out moisture in a flue that is at building temperature. This problem is probably capable of solution by discharging the scrubber exhaust into a flue that also receives boiler gases, or by discharge through a separate duct with admixture of building air. Other solutions are also possible. The schematic arrangement of a gas scrubber (Peabody) in the basement following an incinerator is illustrated in Fig. 6. In case of power failure during a burn, damper A must open automatically to vent the furnace.

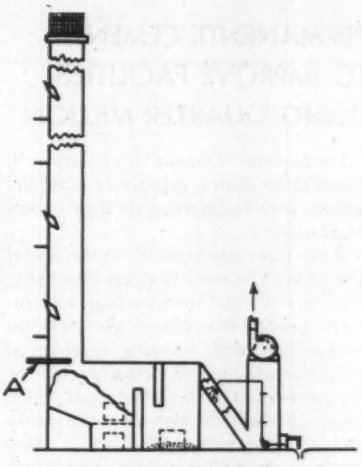

Fig. 6. Incinerator with gas scrubber.

Conclusions

1 The flue-fed incinerator in apartment buildings fills an important need, with convenience and economy to the tenants, building managements, and to the community in refuse disposal.

2 Improvements to the flue-fed incinerator have been demonstrated in recent years and our knowledge of refuse incineration has increased, notably in regard to hopper locking, auxiliary gas firing, overfire air jets, and the use of flue-gas scrubbers.

3 Additional investigations and carefully conducted field trials are needed to develop information in the following areas among others:

- *A* Furnace configurations.
- *B* Control of flue-gas leakage into buildings by preventing (*1*) the plugging of spark arresters, (*2*) back pressure from roof settling chambers, (*3*) negative pressures in hallways caused by exhaust fans, and (*4*) other causes.
- *C* Performance of incinerators with by-pass flues.
- *D* Manipulation of furnace charges to complete burnout without increase of atmospheric pollution.
- *E* Performance of built-in incinerator settling chambers.
- *F* Gas scrubbers in basement installations.

4 Codes and standards of design, construction and performance of flue-fed incinerators should take cognizance of the possibilities of new designs and improvements. Encouragement should be given by air-pollution control officials and others to those who are trying to advance the art.

Acknowledgment

In addition to those whose co-operation was acknowledged in the three previous papers resulting from the project, the writer wishes to express appreciation to officials and staff of the Allegheny County Bureau of Smoke Control, the Milwaukee County Department of Smoke Regulation, and the New York City Housing Authority for the opportunity to inspect incinerator installations.

Mr. Ivan P. Hersh, assistant research scientist, measured flue and building drafts, and Mr. Joseph Tolciss, associate research scientist, assisted with the manuscript.

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FABRIC FILTRATION OF INDUSTRIAL GASES

(*Continued from p 247*)

bular filter bags are hoped to lead ultimately to the use of higher filter ratios and to more precise design procedures.

Perhaps most urgent, however, is the need for information on the mechanisms of failure of high temperature fabric media in industrial usage. Commercial glass fabrics have displayed resistance to abuse in some applications that imply that simple mechanical wear at high temperatures may be overrated as a factor contributing to failure. Other considerations such as the presence of minute quantities of corrosive agents, exposure to cyclic temperatures and intermittent condensation, and localized stress concentrations must be assessed to establish basic criteria for development of improved media.

Acknowledgments

Much of the information included in this report was accumulated through contacts with air pollution research workers, manufacturers and users of air filters, consultants specializing in air filtration, air pollution control officials, and manufacturers of filter cloth and related products. The sincere appreciation of the authors is extended to each of the individuals whose help made this report possible.

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PERMANENTE CEMENT TO IMPROVE FACILITIES USING QUARTER MILLION

Permanente Cement Company will spend more than a quarter of a million dollars here to improve its dust collection facilities.

A contract has been let to the Metal Products Division of Koppers Company, Inc., to build and install a huge electrostatic precipitator which, when used in conjunction with existing mechanical collectors will recover virtually all of the dust generated in the kilns—dust which otherwise might be blown out the stacks and over the surrounding area. Electrostatic precipitators are highly efficient devices to remove entrained particles from plant gas streams or stacks.

Delivery of the precipitator is to start in five months and it is expected to be in operation later in the year.

Installed on Kilns

The precipitator will be installed on two wet process kilns. Since cement production must be maintained, Koppers will completely build the precipitator adjacent to the existing flues without affecting operation of either kiln. Final connections to the flues will require a shutdown of only four days on one kiln and six days on the other.

In operation, the flue gas streams will be directed through the precipitator which gives a high-voltage electrical charge to the entrained particles. The gas, with its charged particles then moves toward a series of collector plates. Because the collector plates carry on opposite electrical charge, they attract the entrained particles and hold them. The plates are cleaned by periodic rapping. The Permanente precipitator will have transisterized, fully-automatic power control units.

The Permanente precipitator will be the third big "dust collector" of the electrostatic type to be installed by Koppers for West Coast industry in the last year. The other two recover soda ash at paper company installations at Antioch, California, and Hoquiam, Washington.

CALENDAR

June 6–8	Second National Congress on Environmental Health, Ann Arbor, Michigan.
June 11–15	**54th Annual Meeting of APCA, Hotel Commodore, New York, New York.**
June 19–23	Air Cleaning Institute, Harvard University School of Public Health, Boston, Massachusetts.
June 25–30	Summer Engineering Seminar on Electrical Precipitation, Pennsylvania State University, University Park, Pennsylvania.
Sept. 21–22	East Central Section Annual Technical Meeting, Louisville, Kentucky.

SECTION HI-LITES

Dr. Allen D. Brandt, Manager of Industrial Health Engineering, Bethlehem Steel Corporation, Bethlehem, Pennsylvania, was the speaker at a recent meeting of the Niagara Frontier Section of APCA. In the introduction to his talk entitled "Air Pollution Problems in the Steel Industry," Dr. Brandt traced the origin of the present day problems due to mechanization and distinguished between air pollution and pollutants, pointing out that pollutants do not always result in air pollution, and air pollution is a "condition" which becomes a problem as it affects people.

He then reviewed the controlling of pollutants from the following sources: coke plants, sintering plants, blast furnaces, open hearth furnaces, electric furnaces, and basic oxygen furnaces.

EXHAUST EMISSIONS

(*Continued from p 253*)

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APPENDIX

Total Sample Traffic Cycle

Mode	Elapsed Time, Sec	Accumulated Time, Min and Sec
Acceleration 0–60	20	20
Cruise 60	15	35
Deceleration 60–50	5	40
Cruise 50	15	55
Deceleration 50–20	15	1–10
Cruise 20	15	1–25
Acceleration 20–30	10	1–35
Cruise 30	15	1–50
Deceleration 30–0	10	2–00
Idle	30	2–30
Acceleration 0–30	20	2–50
Deceleration 30–15	10	3–00
Cruise 15	15	3–15
Acceleration 15–40	20	3–35
Cruise 40	15	3–50
Deceleration 40–0	10	4–00

TI-7 COMMITTEE REPORT

(*Continued from p 240*)

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13. Manufacturing Chemists Association, Washington, D. C. *Air Pollution Abatement Manual.*
14. *Air Pollution Handbook*, Edited by Stanford Research Institute, McGraw-Hill Book Company.

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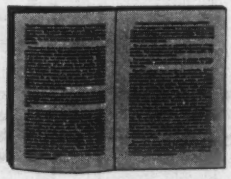

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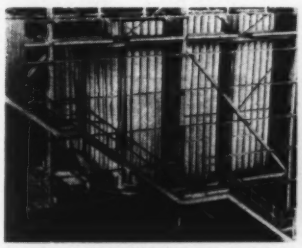
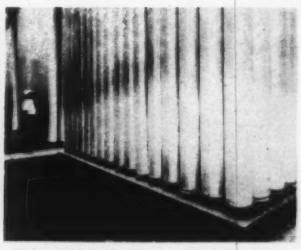
...STEVENS Fiber Glass Filter Fabric Clinic is available for research and development on a confidential basis

...names of fabricators of filter bags made with STEVENS SLKN™ glass fabric will be supplied upon request



Stevens' glass filter bags are gaining widespread acceptance as media to clean industrial plants' gas and smoke exhaust and thus reduce air pollution and smog.



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